Control ENGINEERING

INSTRUMENTATION AND AUTOMATIC CONTROL SYSTEMS

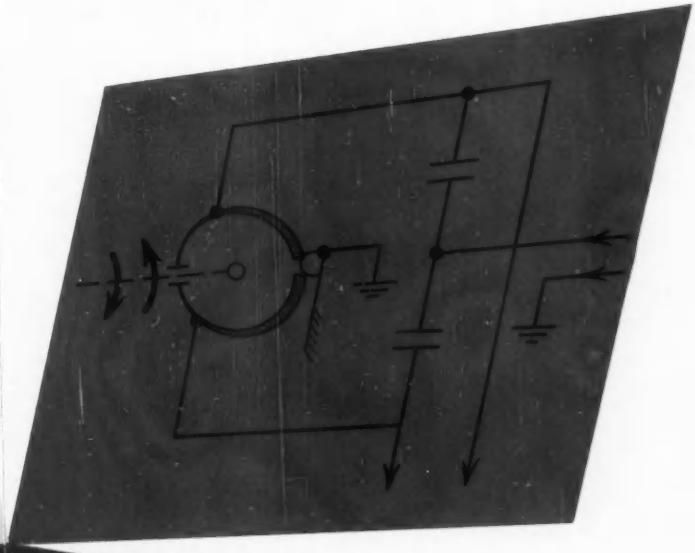
A McGRAW-HILL PUBLICATION

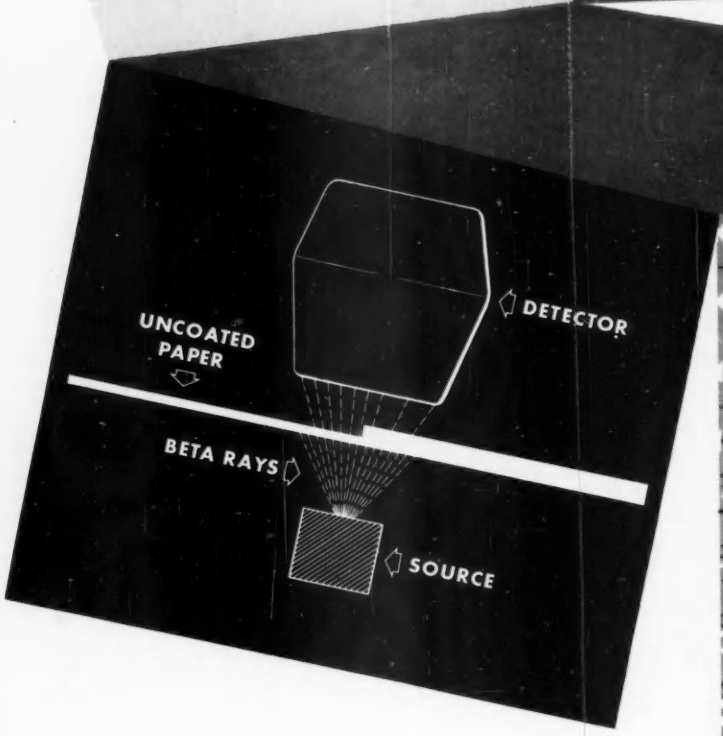
PRICE 50 CENTS

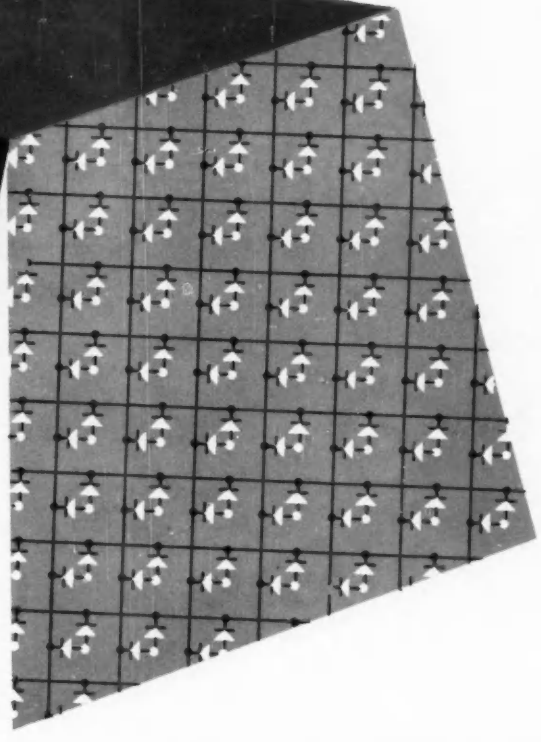
DECEMBER 1955

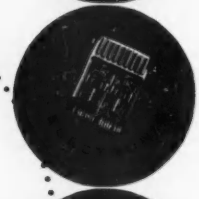
IDEAS AT WORK

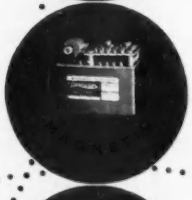
IN SERVO DESIGN
CIRCUIT VERIFICATION
COATING CONTROL

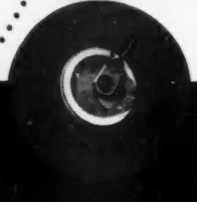












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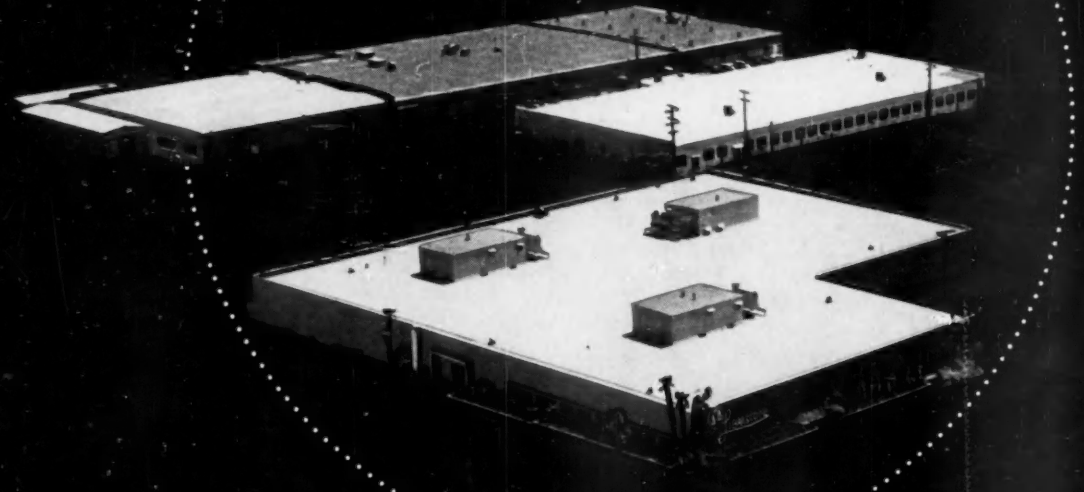

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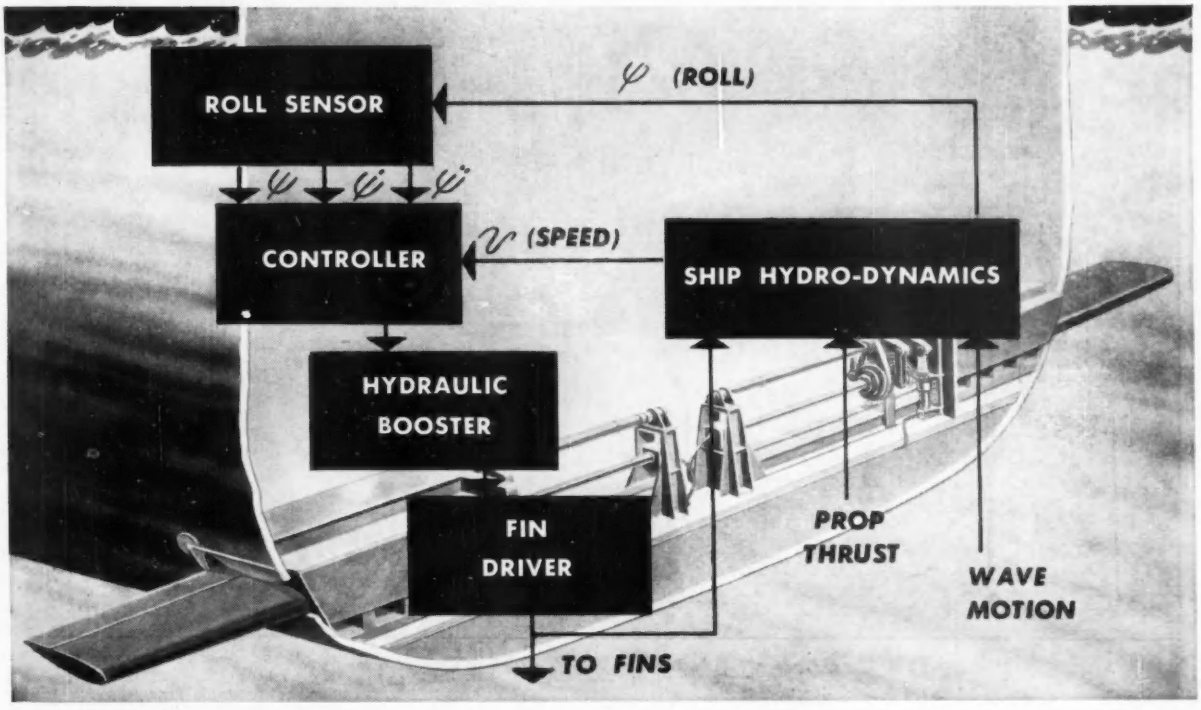
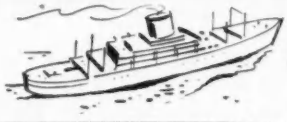
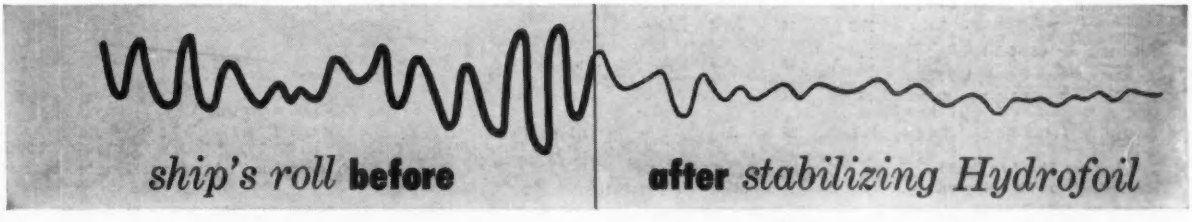




example: **How to make a ship behave**



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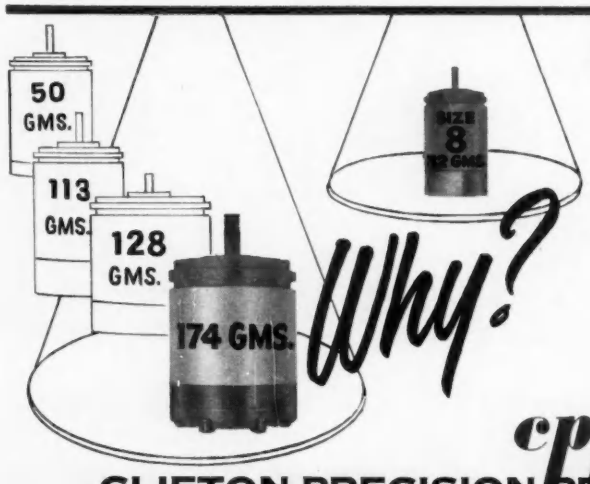
Transmitter	CGC-8-A-7	Rotor 1 Phase	26	100	.50	54+ j260	37.0	Stator 3 Phase	11.8	12+ j45	15+ j3.5	11.8	8	200	7
Control Transformer	CTC-8-A-1	Stator 3 Phase	11.8	90	.230	28+ j110	24.7	Rotor 1 Phase	23.6	220+ j740	246+ j60	143	8.5	400	7
Control Transformer	CTC-8-A-4	Stator 3 Phase	11.8	37	.091	67+ j270	59.5	Rotor 1 Phase	24	508+ j1680	640+ j190	381	9.2	400	7
Resolver	CSC-8-A-1	Stator 2 Phase	11.8	84	.268	38+ j136	27.0	Rotor 2 Phase	23.2	280+ j600	344+ j75	230	11	400	7
		Rotor 2 Phase	26	39	.430	280+ j600	230.	Stator 2 Phase	10.6	38+ j136	70+ j29	27.0	20	180	7
Repeater	CRC-8-A-1	Rotor 1 Phase	26	100	.50	54+ j260	37.0	Stator 3 Phase	11.8	12+ j45	15+ j3.5	11.8	8	200	30' *
Differential	CDC-8-A-1	Stator 3 Phase	11.8	85	.21	27+ j120	25.0	Rotor 3 Phase	11.8	38+ j122	47+ j14	36	9	200	7 Rotor 7 Stator

Total Null max. 20mv for each unit

Also available in 115v 400 cy. primary, 90v secondary Transmitters, C.T.'s, Receivers

*Torque 2600 mg.-mm./degree from CGC-8-A-7



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Control ENGINEERING

DECEMBER 1955

INSTRUMENTATION AND AUTOMATIC CONTROL SYSTEMS

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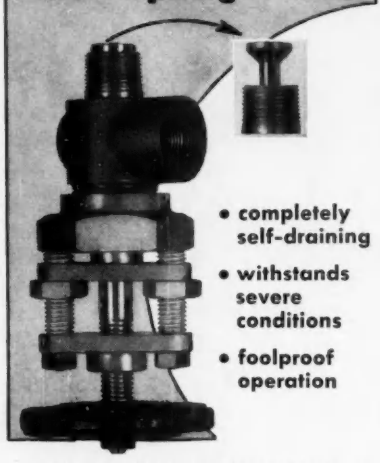
PRINT ORDER THIS ISSUE 28,313

New!
Jerguson Drain or Sampling Valve



- completely self-draining
- withstands severe conditions
- foolproof operation

The new Jerguson No. 23 Drain or Sampling Valve is completely self draining, for the valve stem seats on the outside of the valve body. It is ideal for installations where it is desirable to have the valve seat inside the wall of a vessel in order to prevent the typical condition of liquid remaining in the nipple and valve inlet.

This rugged, new Jerguson Valve has outside screw and yoke construction to meet high temperature or corrosive conditions where inside threads cannot be tolerated. The efficient outside thread design eliminates possible freezing and allows the valve stem to work freely at all times. The No. 23 Valve provides foolproof operation because the stem is constructed with a left-hand thread, thus allowing the valve handle to operate in the normal direction of standard valves.

The No. 23 is recommended for pressures up to 4000 lbs. @ 100° F. or 1000 lbs. @ 750° F. Standard with ¾" N.P.T. Male inlet and ¾" N.P.T. Female outlet. Optional features include construction with an additional connection for such uses as a steaming out line, or with a reamer on the end of the stem to break away encrusted matter which may have collected on the inside vessel wall.

Write for data unit and complete details.

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SHOPTALK

LET'S DO IT YESTERDAY

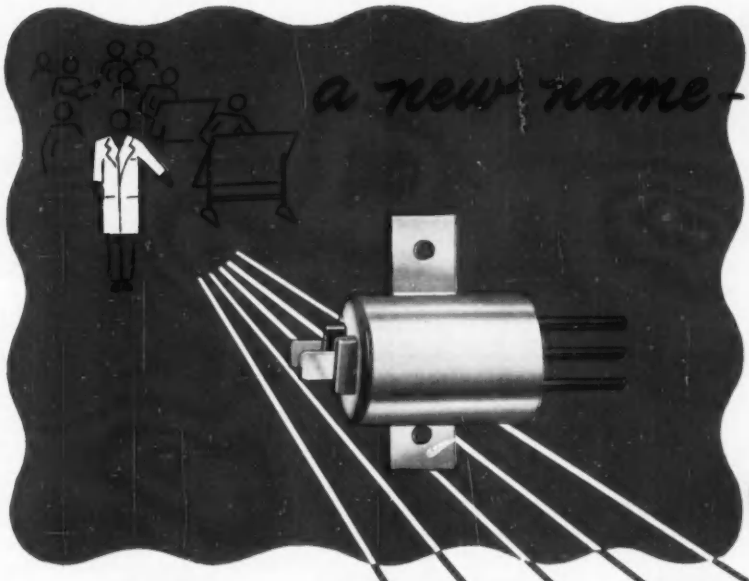
The two stories that open the *What's New* section this month are good reasons why planning feature articles for CONTROL ENGINEERING can never be far enough ahead. Consider our comprehensive series on Basic and on Applied Digital Techniques (Basic No. 3 is on page 60 and the start of the Applied series on page 40). They were planned to prime new users of pulse equipment for the work they face. And now in the news are two great industries—banking and railroading—already well launched into the digital field. Not that we expect a dramatic upsurge in readers at mahogany desks behind potted palms. Or on cabooses. But we wouldn't be surprised. Incidentally, more than coincidence is behind these field doings and our feature planning. One of our strong advocates of the digital series was Dr. Jerre Noe of Stanford Research Institute. Jerre went on to author the very first article in our October issue. But it remained for Charley Scarlott, manager of SRI's technical information service, to tip us off last summer. Jerre had to sneak writing time from a heavy workload that includes readying a new (and newsworthy) accounting machine for Bank of America.

Charley Scarlott (center) tips off Bill Vannah, while By Ledgerwood nods a knowing head

NEITHER FLOOD, NOR RAIN . . .

On Oct. 15 Managing Editor Lloyd Slater saw the water roaring off his Weston, Conn., hillsides and wondered how the nearby Perkin-Elmer plant was faring. Three days later, when he finally fiorded into New York City, he called P & E ad man Chuck Miller for details. They were so vivid and so abundant that Chuck asked P. R. man Charley Dayton to tote the makings of the yarn on page 28 to our office. Look below to see why we were amazed to have this help from Chuck and Charley.

This is what happened to Chuck and Charley (and wives) on the night of the flood near Ridgefield, Conn.



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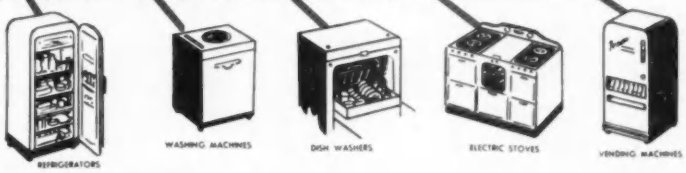
The NEW GUARDIAN ALL-PURPOSE RELOID*

* a switching device actuated by a plunger combining functions of a relay and a solenoid.



totally enclosed to resist impact, dust and moisture . . . built to outlast your product!

It's here—a towering achievement in the fields of electrical and electronic control—the new Guardian RELOID! An *exclusive* development of Guardian Electric, the new Guardian RELOID has been hailed as a highly valuable contribution to the Science of Circuitry Design. Positive in action—flexible in application—compact—totally enclosed—lightweight—dependable for long life operation—priced extremely low.

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Standard voltages. Available in either A.C. or D.C. for any specific voltage from 6 to 115.

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CONTACTS

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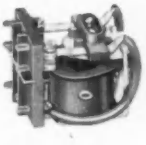

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Component & Instrument Department

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FEEDBACK

He who seeks . . .

To the Editor—

Do you know of any colleges which offer extension courses in automatic control theory? Correspondence courses? I know of several which offer resident instruction, but I can't afford to take the time to attend.

J. H. Ware
Instrument Engineer
Kaiser Aluminum Corp.
Baton Rouge, La.

To the Editor—

The recent survey of the curricula of 67 accredited engineering colleges and universities by the Instrument Society of America's Education Committee has called to my attention the possibility of a university offering control technology courses by correspondence. My degree is in Mechanical Engineering and I am weak in electronics and desire to embark on a planned study program of higher mathematics, electronics, and control technology.

I will not be able to take resident instruction and feel that a planned study program with some guidance would be considerably better than haphazard study.

If such a program is available by correspondence, I am sure there are others in the same situation who would be interested. Your investigation of this would be greatly appreciated.

Harold E. Crider
Pensacola, Fla.

. . . shall learn

International Correspondence Courses, Scranton 9, Pa., offers a three-step correspondence course, "Industrial Instrumentations", for instrument mechanics and technicians. However,

• • •

THE PROBLEM FORUM . . .

. . . is particularly busy this month. Several readers answered the problem presented in the October forum. A summary of their answers starts on page 11. A new problem is posed below. What is your solution to it?

Continue to send in problems and answers. Readers whose problems are printed will receive the complete file of answers and enough cash for a tankfull of gasoline. And those whose solutions are printed will receive awards, too.

December's prize problem

A 200 hp dc motor drives an alternator through a gear train. Supplying power to the field of the dc motor to regulate its speed, and hence the frequency of the alternator's output voltage, is a war surplus motor-generator (amplidyne) unit.

With the system carrying only idling load, a sustained thirty kw increase in load is suddenly pulled on the alternator. The motor-generator control unit then requires five to six sec to return the dc motor to desired speed.

1. How can the recovery time be reduced?

2. What per cent increase in transient peak power must the amplidyne unit handle to produce the dynamic performance indicated by the solution to question (1)?

3. Will the necessary increased current cause motor breakdown?

Edwin F. Rutschmann
1306 Marshalldale
Arlington, Texas

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we have not unearthed a correspondence course at a professional engineering level. Of possible aid is the information that the University of London will set up a correspondence course in any subject for anyone, anywhere.

Ambitious control engineers along the Gulf Coast might query the following for extension courses and short courses:

- C. D. Holland, Texas A & M, College Station, Texas.
- Prof. A. J. Keller, Louisiana State University, Baton Rouge, La.
- Louisiana Polytechnic Institute, Ruston, La.
- And the residents of the Sunshine State may contact Prof. Mark Tyner, University of Florida, Gainesville. He conducts, we are told, a control engineering "retread" course for process engineers.

We are working with the Education Committee of ASME's Instrument and Regulator Div. on the problem presented by both readers, for they are not alone in their educational needs. With sufficient support and encouragement, this committee will endeavor to develop course outlines and training aids for small groups that want courses in automatic control at a professional level. And with specific evidence of demand, it may make arrangements to offer the material in a correspondence course. Demonstrate your interest by dropping this editor a note outlining your needs. Ed.

Critique . . .

To the Editor—

The following is a comment on *These Seven Steps Design a Tach Stabilized Servo* by J. E. Kadish, in the August issue of Control Engineering.

The idea that a servomechanism can be designed in handbook fashion is potentially very misleading. Unless all of the original assumptions concerning the problem specification are met, the design procedure may lead to erroneous answers.

As an example, Mr. Kadish assumes that the frequency response is a secondary consideration. In many instrument servomechanisms, this is not true. In particular there is a minimum bandwidth established by the need to accurately follow the input, and there is also a maximum bandwidth necessary to minimize the following of noise. Mr. Kadish's example of radar following is particularly affected by this latter consideration.

In Step 4 Mr. Kadish limits the

transmission of

pressure

information

MODEL 47155

high output

INDUSTRIAL PRESSURE TRANSMITTER

PRESSURE RANGES

Absolute (psi)	0-15, 0-20, 0-30 0-50, 0-75, 0-100
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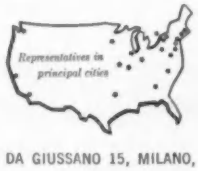
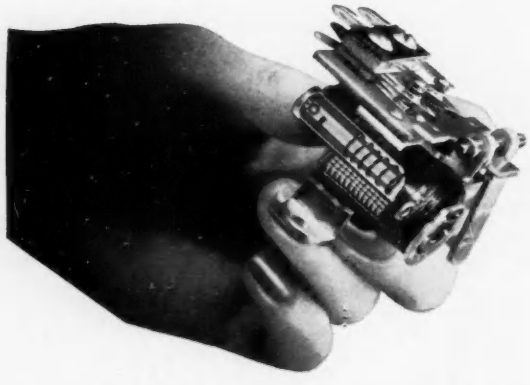


EUROPEAN REPRESENTATIVE: GIANNINI ITALIANA S. p. A., VIA ALBERTO DA GIUSSANO 15, MILANO, ITALY

WHY...

has this time delay relay aroused such interest?



- May be ENERGIZED CONTINUOUSLY . . . does not require auxiliary lock-in circuits . . . a load carrier in itself
- SNAP-ACTION contact speed . . . up to DOUBLE-POLE, DOUBLE-THROW switching.
- SIMPLE HERMETICALLY-SEALED time element . . . long life stability. Not subject to aging or fatigue.
- LOW COST as a unit; even lower considering simplified installation.
- The NAME . . . *Silic-O-Netic* Time Delay Relay . . . MEANING: SILICone controlled, magNETIC flux variation.
- It's NEW . . . the Type "A" *Silic-O-Netic* Relay is a vastly improved model.

STRAIGHT FACTS

Time Delays . . . from ¼ to 120 seconds.

Small size . . . Overall dimensions: 2 1/16" x 2" x 1 9/16" . . . Weight 3 ozs.

Operation . . . Hydraulic-magnetic principle providing positive contact operation, good contact pressure.

Contact capacity . . . 3 amp. at 120 volts, AC (Non-inductive load) . . . D.P.D.T.

Write for Bulletin T-5002

HEINEMANN

ELECTRIC COMPANY

162 Plum St., Trenton 2, N. J.

FEEDBACK

tachometer-stabilized system to a velocity constant of 200. It should be brought out, however, that much higher velocity constants can be achieved by also employing compensating networks in the dc section provided by the demodulator-modulator of Figure 5. In fact, by employing this means and by considering the possibility of adding inertia to the motor, a great range of natural frequency and velocity constant can be obtained, including very high velocity constants at very low natural frequency.

I believe Mr. Kadish will find that the figure of merit of a motor can be expressed with greater meaning as (stall torque)²/ Motor Inertia.

It would be interesting to find out what other readers' reactions are to "handbook" procedures for servomechanism design. I do not feel that servomechanism design can be reduced to handbook procedures except for the most elementary applications.

A. M. Fuchs
Baltimore, Md.

. . . and author's reply

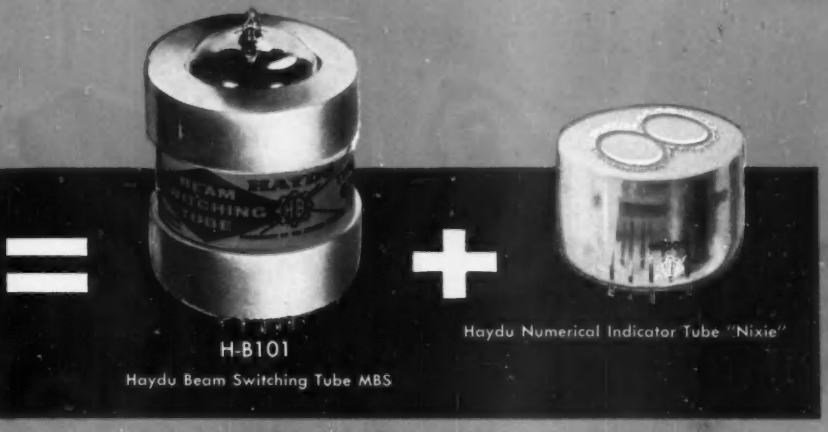
TO THE EDITOR—

The comments by Mr. Fuchs on the tachometer stabilized servo article are interesting, but fundamentally in disagreement with some of the writer's beliefs.

There is a somewhat esoteric attitude prevalent among many servo people to the effect that their particular specialty cannot be worked at without some very profound study and background. It was disagreement with this attitude that prompted me to take a simple case of "designing a relatively low-performance" servo (to quote the article) and attempt to demonstrate that the steps were straightforward, and really could be followed almost in "handbook fashion". Admittedly, the presentation itself may not have proven my point as well as I would like. Probably a more extensive discussion of bandwidth would have measurably improved the presentation. Nevertheless, I do maintain that one can arrange such servo design work in sequential order and tackle it in this manner. Furthermore, I believe that by an extension of assumptions of design parameters, one can evolve a "handbook fashion" design procedure for servos far more complex than the very elementary ones described in the article. In view of our current national shortage of

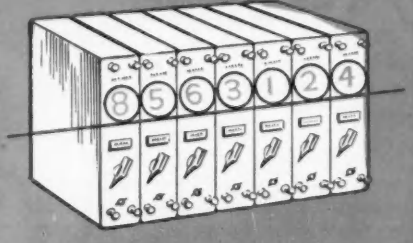
New COMPONENTS PRODUCE MICRO-SECOND

Vari-Count



Two outstanding basic electron components . . . Haydu's "Beam Switching Tube" and "Nixie" the numerical indicator tube . . . are combined to make possible this *versatile* new instrument.

- **VARI-COUNT**
  - Static to megacycle counter distributor
  - Microsecond electronic preset
  - Microsecond variable scale output
  - Microsecond recycling
  - Microsecond clearing
  - Preset gating
- **BEAM SWITCHING TUBE** (6700)
  - Replaces 20 Tubes
  - Megacycle counting 0-9
  - Megacycle preset
  - Low power consumption
  - Electronics most reliable distributor
  - Pentode "working" output
- **NIXIE** (HB106)
  - 1" x 1"
  - 10 digit 0-9 gas indicator tube
  - "Two-dimensional"
  - In-line readout
  - Common anode prebiasing
  - Low power



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Write for complete technical data to:

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BROTHERS OF NEW JERSEY

PLAINFIELD, NEW JERSEY

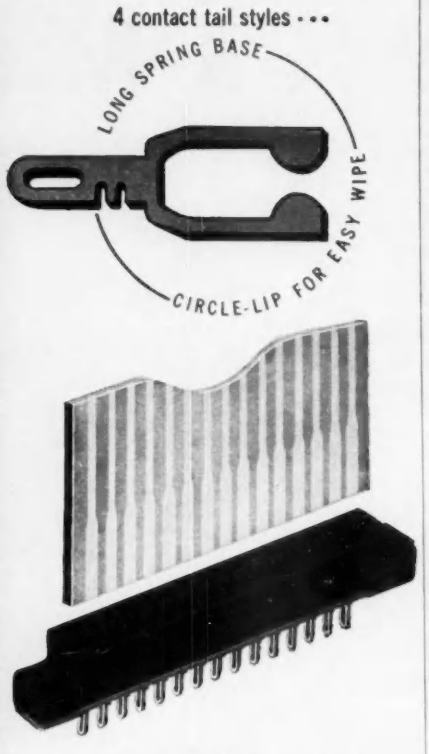
SUBSIDIARY OF BURROUGHS CORPORATION

AMPHENOL

PRIN-CIR
CONNECTORS

revolutionary
NEW
contact design

IN
AMPHENOL
PRINTED CIRCUIT
CONNECTORS



Prin-Cir connectors are the result of careful design work by AMPHENOL Development Engineering. They feature compact bodies and a new contact design that is greatly superior to any available for printed circuit applications.

Prin-Cir contacts can't be set, can't be overstressed when used with standard .061" to .071" boards, have very low millivolt drop and extremely long life. This contact has an extra-long spring base and a circle-lip for good wiping action.

Prin-Cir connectors are available with 10, 15, 18 and 22 contacts in four contact tail styles: Standard Eyelet, Wire Wrap, Pin and Open End. They may be ordered with one or more polarizing keys in any contact location.

Bodies are molded of an improved version of AMPHENOL blue dielectric and contacts are gold-plated.

Write for special Product Bulletin

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AMPHENOL

FEEDBACK

engineers, I feel that it is rather important to make many design procedures simple and somewhat routine in order to enable persons of lesser experience to be of more use to their engineering group. No implication is intended that work accomplished by these less experienced engineers needs no monitoring. The desire to limit the article to elementary servos led to the omission of discussion of methods for altering velocity constant and bandwidth. Mr. Fuch's comments about compensating networks and motor inertia are certainly applicable and well taken.

J. E. Kadish
American Machine & Foundry Co.
Boston, Mass.

Reader response has been so enthusiastic to the handbook-like article that we have scheduled for publication many more on specific control problems. We do urge the reader, though, to check the original assumptions on which are based the analyses presented in the articles. Ed.

Idea for inventors' hall of fame

TO THE EDITOR—

We like to make the following suggestion as I know you are always open to new ideas:

Each engineer who is an original thinker likes to think of the number of patents (or assigned patents) in his name as a measure of his relative power as an *inventor*. Suppose your magazine sent a letter to each subscriber, asking him and his associates to list (for confidential filing) the patent numbers assigned to him. Then on a page entitled "A Salute to the Inventors Among Us" the man's name, company, and quantity of patents would be indicated. Those in the upper 10 per cent would come first, with gold star mention. No doubt it would take several issues to list everyone. The list should probably be reserved for those with three or more patents to keep from being too lengthy.

I have never seen the above done before, but am sure that it would bring some small recognition and be appreciated by those involved. It could be made more interesting to first give honorable mention to such famous men as Edison, Stienmetz, etc, and the number of patents in their name.

Jerrold B. Winther
Alectric Mfg. Co.,
Kenosha, Wis.

Help the article clipper!

To the Editor—

Would it be possible to print your magazine so that all the articles and editorials are backed up or separated by ads? I don't save the whole magazine—I clip articles and drop them in file folders. Many times it isn't possible to do this when one interesting article is printed on the back of another. Perhaps other readers have the same trouble.

If adopted it might be played up as another innovation or improvement in reader service. Likewise, maybe advertisers would like to locate their material between articles where it would get more attention.

W. Jewsbury
Instrumentation Group Engineer
Bell Aircraft Corp.,
Buffalo, N. Y.

The problem comes up repeatedly. There are a couple of ready solutions. The first is easy—fill in and send to us the reprint coupon, published periodically, for reprints of articles that you cannot obtain intact by clipping your copy. The second calls for the editors to back the last page of each right-hand closing article with a one page article or design note. We cannot adopt this solution right away, but we will as soon as possible. The separation of feature articles with ads raises other problems that we would be glad to discuss in person but would rather not belabor in this column. Ed.

SOME ANSWERS TO THE PROBLEM FORUM

October's Problem: Convert the 0-30 mvac output of a strain gage bridge to a proportional frequency. Specifications:

Frequency band, 500 to 6,000 cps
Resistance vs. frequency, linear within 1-2 per cent of full scale
Record on magnetic tape

From: Jack W. Schmidt, General Motors Corp., Indianapolis, Indiana

Selected Solutions:

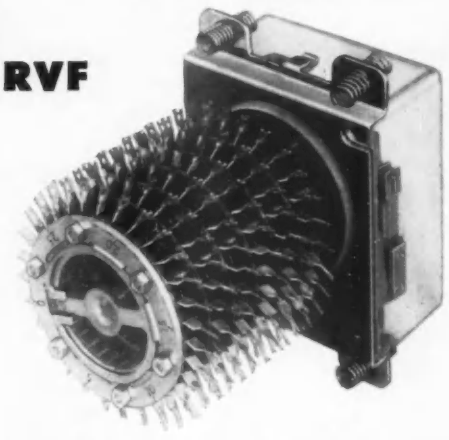
(1) In the August forum *R. K. Dickey, Berkeley, Calif.*, offered several circuits for integrating a voltage. Three of his circuits will develop pulses at a rate proportional to voltage by charging and discharging the timing condenser of a blocking oscillator.

(2) *George E. Row, Apt. 7, 644 E. 22nd St., Indianapolis 5, Ind.*, proposes tuning an oscillator with a servo motor. It would be driven by the amplified difference between the out-

Maximum Switching.. MINIMUM SPACE

24
48
110
VOLT DC
ROTARY
SWITCH RVF

30 Points
6 Levels
Single
Wiper
or
15 Points
12 Levels
Twin
Wipers



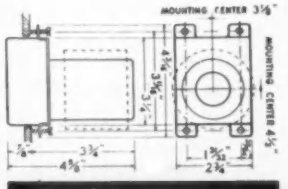
A "find" for Systems Designers

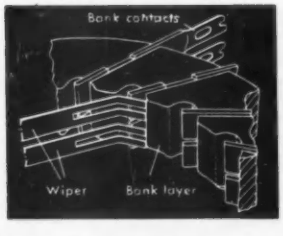
Combining outstanding quality and craftsmanship with the most advanced principles of design and construction, the R V F Rotary Switch features greater reliability, smoothness of operation, precision, speed, longer life, compactness and light weight as standard specifications.

1. Built-in silicon carbide spark suppression on 24 and 48 volt standard switches.
2. Each switch is shock mounted with full spring suspension for shock and vibration isolation.
3. Bank and drive mechanism completely dust-proof—in transparent cover—permits easy inspection.
4. Rotor index visible from top or bottom.
5. 10,000,000 revolutions with no adjustment.
6. Bifurcated wiper contacts.
7. And more . . .

Shorting type wiper contacts . . . non-bridging . . . connecting two individual adjacent contacts. Interrupting springs of special contact alloy . . . needs no field adjustment. Spring driven switch rotates in one direction . . . eliminates fly-back spring. Switch overtravel is impossible . . . positive stopping at any selected point.

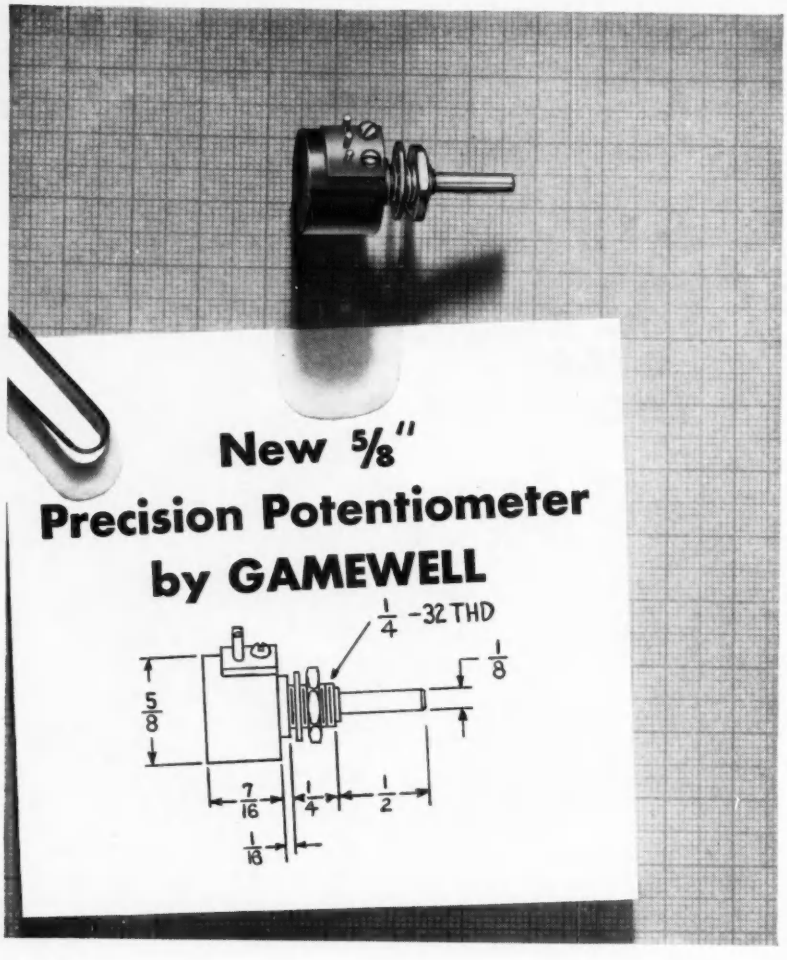
USAGE: Automatic controls . . . Scanning . . . Coding . . . Register Storage . . . Programming . . . Sequence Operation . . . Pulsing . . . Tele-metering . . . Computors.





Detailed specifications available on request.

NORTH ELECTRIC COMPANY
537 South Market Street, Galion, Ohio



Here is a 5/8" potentiometer that offers you the extreme precision found in larger sizes of Gamewell Potentiometers.

Body is of anodized aluminum and the shaft is made of stainless steel. Kohlrausch type winding provides excellent linearity and the unit meets MIL-E-5400 specifications as they apply.

The unit can be modified for special mounting, Multiple gangs, higher operating temperatures, and other special features upon request. Write for additional information about this miniature precision potentiometer.

CONDENSED TECHNICAL DATA:

Resistance	*30K ±5%
Min. Resistance	20 ohms
Linearity	*0.25
Electrical Angle	345°
Resolution	*0.09%(1100T)
Test Voltage	1000 RMS
Temperature	105°C
Watts	1
Size	5/8" OD 7/16" long
Torque	0.2 oz.-in.

*Maximum Values

THE GAMEWELL COMPANY
NEWTON UPPER FALLS 64, MASS.

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PRECISION POTENTIOMETERS

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put of the strain bridge and an fm detector that feeds back a measure of the oscillator's frequency.

(3) *R. W. Butenbach, 3717 Sundale Rd., Lafayette, Calif.*, was so taken with Jack Schmidt's problem that he sent in a five-page treatise, complete with schematic and a calibration curve. He, too, suggested driving an RC oscillator with a servomotor.

(4) *Marvin Weiss, Norden Laboratory Corp., 121 Westmoreland Ave., White Plains, N. Y.*, wants to tune the oscillator with a variable air capacitor driven by a D'Arsonval movement connected to the rectified output of the strain bridge. He writes, "The capacitor tunes an oscillator from 100,500 cps to 106,000 cps. Over such a small range the frequency variation can be made quite linear. This oscillator is beat against a 100,000 cps crystal oscillator and the output passed through a low-pass filter."

(5) *A. B. Kaufman, Arnoux Corp., 11924 W. Washington Blvd., Los Angeles 66, Calif.*, advises, "Jack Schmidt's problem . . . is solvable by commercially available components . . . such as employed in aircraft and missile telemetry systems for flight test of vehicles. They are available from Raymond Rosen Engineering Products, 32nd and Walnut Sts., Philadelphia 4, Pa."

(6) Alert *Robert Spiegel, Project Engineer* at the suggested source, writes,

"Our Bridge Activated Oscillator supplies excitation to the strain gage bridge at its own operating frequency, amplifies the bridge output, and frequency modulates an LC oscillator with the amplified signal. Use with a 120 or 300 ohm bridge having a maximum output of 2.5 to 5 millivolts per volt of excitation is typical.

"In order to meet the requirement of 500 to 6,000 cps frequency band, I suggest changing the frequency of an oscillator operating at 14.5 kg plus or minus 7½ per cent to the desired band by first tripling, to achieve 5,500 cps total excursion, and then heterodyning to the final operating frequency. Thus, the bridge-activated oscillator operates in its factory designed frequency band, where the linearity is typically plus or minus 1½ per cent of the best straight line, and is transposed to the operating frequency by a scheme which does not introduce frequency modulation distortion."

which way* to measure jet engine performance?

KOLLSMAN PRESSURE RATIO THRUSTMETER
used on Convair's F-102 and McDonnell's F-101

thrustmeters

to indicate PRESSURE RATIO...to indicate DIFFERENTIAL PRESSURE

Actual photograph

KOLLSMAN is in production...

on components for BOTH TYPES—for Remote or Direct reading

For over a quarter century, Kollsman has been making precision pressure sensitive mechanisms using displacement type diaphragms. This diaphragm can be called the heart of a thrustmeter pressure indicating system.

Our long experience making displacement type diaphragms guarantees reliable thrustmeters.

Proven Kollsman displacement type diaphragms, when fitted with Kollsman Synchrotels, comprise the transmitters for remote indicating types. Thousands of Synchrotels are now in use in other applications equally demanding of accuracy and durability.

Tailor-made Thrustmeters can be supplied for any engine-airplane combination. Write for complete technical information.

TYPICAL SYSTEM OPERATIONAL DATA

1. Accuracy: .015 in 100% of readings at room temperature.
   .025 in 85% of readings at −55°C and +70°C.
   .035 in 15% of readings at −55°C and +70°C.
2. Altitude: No specific limitation.
3. Power: 115V, 400CPS, single phase, 18VA
4. Pressure Ratio Range: 1.2 to 3.4
5. Pressure Ranges (operating):
   Pt_2=2 to 50" Hg. Abs.
   Pt_7=2.4 to 100" Hg. Abs.
   Pt_7-Pt_2=0.4 to 70" Hg.
6. Temperature Range: −55°C to +120°C
7. Weights:
   Transmitter: 2.2 lbs.
   Indicator (including integral amplifier): 1.8 lb.
8. Response: Full Range in 7 seconds.

**The Pressure Ratio System has advantages for indicating optimum climb and cruise throttle setting, whereas the Pressure Differential System has a definite advantage at take-off.*

Kollsman activities cover these seven fields:

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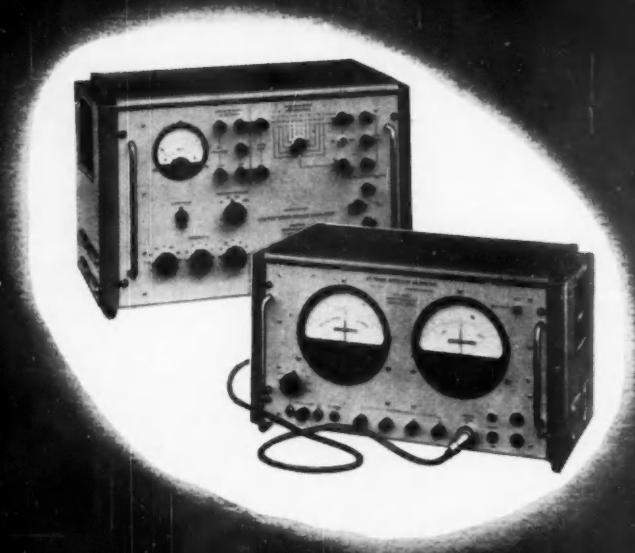
Out of this world



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★ [illegible] A.C., D.C. or carrier [illegible]

★ Plots [illegible] courtesy Nyquist diagrams

★ Covers 0.1 c/s to 1,000 c/s

★ Independent of harmonics, noise & spurious frequencies

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For servo design and testing, the Solartron Transfer Function Analyser really is "out of this world". G.P. manufacturers everywhere are getting way ahead and every mail brings reports of new applications for which the T.F.A. has proved ideal. Cable Solartron if you want our engineer to give you a demonstration, or write for fullest information.

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HENRI-GEORGES DOLL
prospects in control

There is a strong and growing conviction among educators that tomorrow's creative control engineer will rely more on broad scientific background than on specific engineering skills. Henri-Georges Doll and his accomplishments might well serve as a model for this theory.

Consider Mr. Doll's background: science, engineering, and finally graduate work in fundamental sciences at two of France's outstanding technical schools. And then a career in research with two geophysical prospecting firms from 1926 until World War II. His pre-war accomplishments in his chosen field are represented by basic patents and papers on subsurface geophysical prospecting.

With the advent of World War II, Doll, a citizen of France, saw active duty as an officer in the field artillery of the French Army until he was called from the field to lead the development of a much-needed mine detector. He accomplished the assignment, only to see prototype, data, and records destroyed when he escaped to Africa and, eventually, Houston, Texas, after the fall of France. In Houston, with the financial and technical assistance of the Schlumberger Well Surveying Corp., he and Dr. Charles B. Aiken built a model that was convincingly demonstrated to the War Department. A model was used to find the silver dumped into Manila Bay at the time of the Japanese conquest.

Seeking a significant defense need, Doll and his group found it in a pioneer application of automatic control to weapons. For the effort, a non-profit subsidiary, Electro-Mechanical Research, Inc., was established by Schlumberger with Doll as president. One of the most significant EMR projects early in the war was an automatic anti-roll stabilizer for homing bombs. The system has been described in a history of weapons as "novel in those days in that it worked." Needless to say, this is an important objective for any control system. But much more important, considering the era, were the control techniques conceived and the method of analysis used.

No bombs to play with

In devising the system Doll did not know of, and hence bypassed, the usual linear combinations of proportional and rate control actions. And with no bombs to play with, he could not solve the problem by cut-and-try. He wrote the transient equations that described the rotational dynamics of a bomb

stabilized by movable fins. Then, from phase-plane studies he developed a predictor circuit incorporating a memory and acting through a reversing clutch on the anti-roll fins. Subsequently, while studying improvements on autopilots, he developed a new control using an optimized non-linear switching function generated by an electro-optical predictor.

Proved in Wind Tunnel

This milestone work in non-linear control was proved in a home-made wind tunnel in the latter part of 1942—a time when the routines of servomechanism analysis and synthesis were just being developed to break the bottleneck of handling linear transient equations. The theory applies equally well to servo and process control systems.

After the war, Henri-Georges Doll turned his attention back to geophysical measurements. But late last year his irrepressible interest in control again came to the surface. This time the parent company formed Schlumberger Instrument Co. in Ridgefield, Conn., with Mr. Doll as president.

Within the next few months members of his group will present to ASME and AIEE a series of papers on the conception, implementation, and performance of the optimum non-linear control mode.

HARNESSING THE POWER OF THE POLES...

Berkeley MAGNETICS

a totally NEW *concept of industrial instrumentation*

Berkeley FERRISTOR* Circuitry

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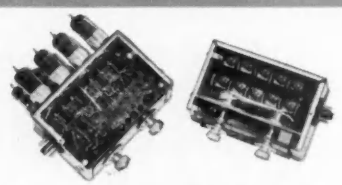
RELIABILITY—designed for *continuous* duty!

RUGGEDNESS—immune to shock, vibration, overload!

SIMPLICITY—installation, operation, maintenance by regular plant personnel!

Brings You High Speed Counting and Control Without Vacuum Tubes!

Utilizing rugged BERKELEY Ferristors* to perform most vacuum tube functions, new BERKELEY industrial counting and control instruments offer electronic speed and precision **plus** the unfailing reliability, simplicity and long service life of electromagnetic devices:



"TUBELESS" Decimal Counting Unit (right) generates 1/8th the heat of vacuum tube model (left); no component in the Ferristor* DCU operates at more than 25% of its ratings.

○ **CONTINUOUS-DUTY RELIABILITY**—rugged encapsulated Ferristors*, developed and manufactured by Berkeley, are immune to damage caused by shock, vibration, moisture and overloading. They're non-aging, require no filaments, operate at extremely low current and voltage levels; produce little or no heat.

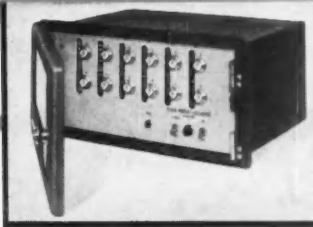
● **INSTALLATION, OPERATION, SERVICING BY REGULAR PLANT PERSONNEL**—no electronic "experts" required! Connections made on clearly-marked terminal strips, with standard industrial wiring procedures. Simple tamper-proof adjustments; sturdy, easily-understood controls!

● **LONG COMPONENT LIFE**—circuits operate at a fraction of component ratings. Elimination of excessive heat ends heat-caused deterioration and instability, permits use of dust-tight enclosures (no ventilation needed).

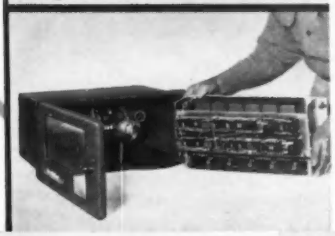
*Trademark

a totally NEW concept of industrial instrumentation

Berkeley Series 5840 Long-Life MAGNETIC Dual Preset Controller



TAMPER-PROOF, dust-tight transparent cover can be locked to prevent re-setting by unauthorized personnel.



SWING-OUT chassis construction simplifies installation, inspection and servicing.

Counts at rates to 10,000 per sec, produces electrical output signals at any two preset totals. Absolute accuracy. Operates from photocells, magnetic pickups, electrical contacts. Built-in DPDT output signal relay operates solenoids, solenoid valves, power relays, other control devices. First signal may be used to slow down operation preparatory to stop at final (second) count, etc. Has only two vacuum tubes (vs. 54 in electronic model), both used in low-level rf oscillator-power supply. Simple marginal test indicates approaching tube failure, permits replacement before failure occurs.

BRIEF SPECIFICATIONS

Max. Count Rate: 10,000 counts per sec

Input Sensitivity: 0.1 ma p-p into 10k load

Output Signal: From built-in DPDT relays; contacts rated at 5 amps (non-ind.)

Accuracy: Absolute

Power Requirements: 105/130 or 210/230 v. 60 cycle, 85 w.

Dimensions, Weight: 18⅞"W x 8¾"H x 13⅝"D; 50 lbs.

Price (f.o.b. factory): Model 5846 (6 digit) $1,295.00.

APPLICATIONS

Control of counting, weighing, sorting, packaging, shearing, metal forming, coil winding equipment; cut-off of motors, turbines, jet engines at precise predetermined rev count or speed, computer timing, etc. Continuous-duty reliability makes new MAGNETIC Preset Controller ideal for all process and production control applications where elimination of costly downtime is a vital factor.

Berkeley Model 7650 Long-Life MAGNETIC EPUT* Meter

Measures events occuring during precise 0.1, 1 or 10 sec time interval, displays results in digital form. Operates from photocell, magnetic pickup or any suitable transducer to measure pressure, temperature, flow, velocity, viscosity, frequency, rpm, or to count events or objects at rates to 40,000 counts per second.

Only three vacuum tubes used (35 in comparable electronic model) in rf oscillator-power supply operating at low levels. Simple marginal test indicates approaching tube failure, permits replacement before failure occurs. Has digital "count-down" time base for precise gating: no adjustment of time base required.

BRIEF SPECIFICATIONS

Count Capacity: 5 digits

Counting Rate: 0 to 40,000 per sec

Time Base: 0.1, 1 or 10 sec

Accuracy: ± 1 event, ± 50 ppm

Input: 0.3 ma p-p into 10k load

Power Requirements: 105/130 or 210/230 v. 60 cycle, 100 w

Dimensions, Weight: 18⅞"W x 8¾"H x 14⅝"D (overall); 55 lbs.

APPLICATIONS

Aircraft, automotive, jet or piston engine test cells, dynamometer test stands; laboratory or production tachometry systems; process control systems; data reduction systems; hydraulic and pneumatic servo testing; acceleration-deceleration determination; measurement of linear or centrifugal speeds, forces, strains; measurement of any optical, electrical, mechanical or physical event occurring during a precise time interval.

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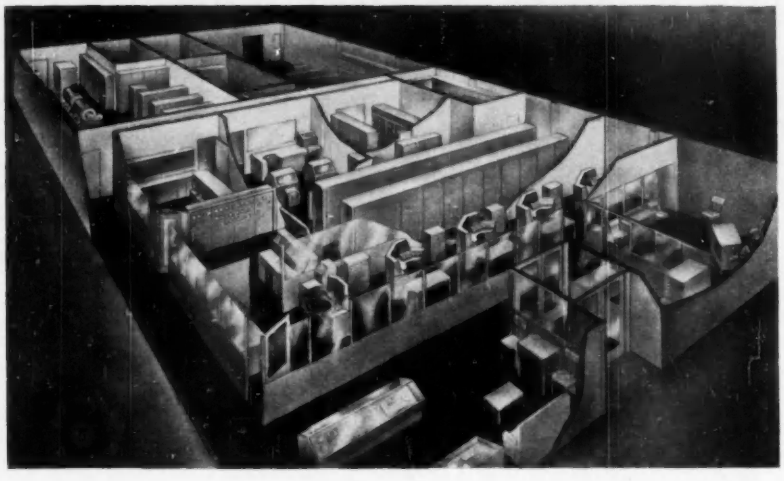


BACK ROOM OF A BANK?

At the left is an artist's conception of the digital equipment that will soon pulse quietly in 37 branches of California's huge Bank of America. Developed by Stanford Research Institute, the system will automatically process 50,000 accounts a day.

Banking Readies for Automatic Service . . .

Five years ago a group of Bank of America executives went to the computer and control systems group at nearby Stanford Research Institute with a problem. Postwar demand on the bank was creating an incredible 23,000 new accounts each month. What automatic approach would solve the giant paper snarl?

Last month the answer came: SRI unveiled its prototype for an electromechanical machine that will automatically service up to 50,000 checking accounts a day.

Bank of America's problem, and even its solution, are hardly unique. Most other large banks have viewed growing business with a certain alarm —and have sought an answer in electronic additions to their existing mechanized data processing systems. Only last June the First National Bank of New York demonstrated a new Burroughs Corp. machine that would optically scan and process into punched cards 7,200 travelers checks per hour. But this remarkable speed was hardly matched by the stately card handling routine that followed.

SRI's ERMA (Electronic Recording Machine, Accounting) has great promise because it will handle a complete transaction automatically, and at split-second speed. Essentially, it is a high-speed digital computing system that will record individual deposits and debit withdrawals, maintain balances, retain transaction details, prevent overdrafts, accept stop-payments and hold-orders, and sort checks. It will also calculate service charges and turn out monthly statements at 600 lines a minute.

How ERMA Works

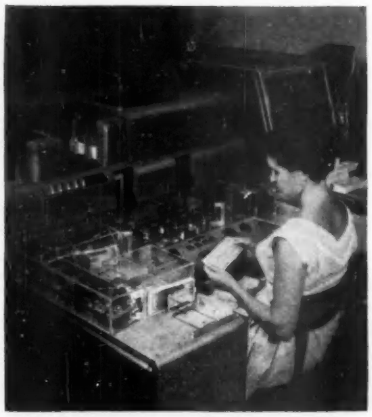
ERMA starts with five input keyboards that look like large adding machines. All checks carry the account number and bank branch in magnetic ink. This information is converted to an electrical code by the input "reader". The operator only has to depress the dollar value and transaction key. This input information is also typed on paper tape.

Consider as the input item a $25 withdrawal. Details on the account's current balance, any "holds" or "stop-payments", etc., are stored on two magnetic drums. The drums—16 in. diam, 1800 rpm, 300-track units that hold up to 600,000 digits—are scanned and the amount in the particular account plus the $25 debit are routed to an arithmetic unit that promptly returns the new balance to the drums. ERMA uses conventional flip-flop circuits to add or subtract up to 11 figure numbers.

SRI's system also includes a more detailed storage file consisting of ten magnetic tapes, each 2,400 ft long. All transaction figures, such as the $25 withdrawal and its date, are transferred from temporary storage on drums to the tape. Since the tape moves much slower than drum speed, this transfer is effected by a shift register. At day's end all tape entries in each account are calculated and checked against drum-held information. And at the end of the business month, tape information is fed into a high-speed printer that prepares a statement for the account holder as well as a permanent record for the bank.

Rapid Printing and Sorting

One special need SRI faced was for a printer that could prepare the huge

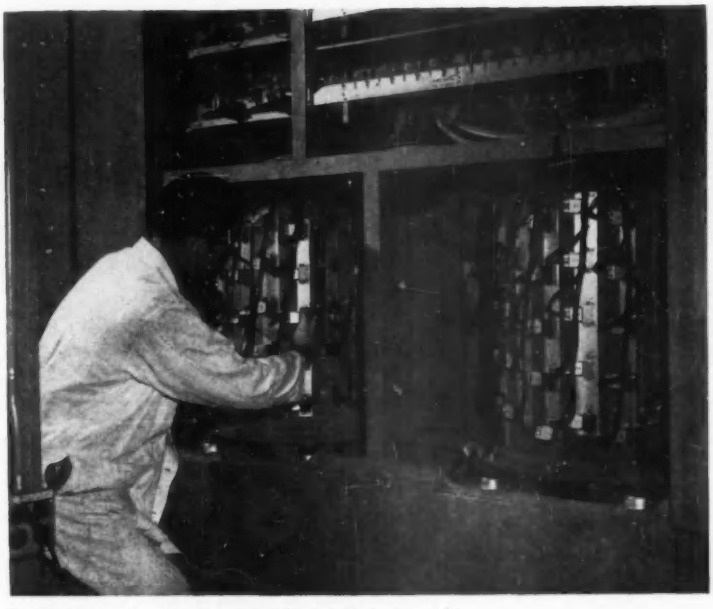


HOW IT KEYS IN DATA . . .

The input keying device will scan magnetically inked account numbers on the checks and speed them, as electrical pulses, into the system.

HOW IT SORTS CHECKS . . .

This high-speed sorter—developed in SRI Control Systems lab—will "read" and file checks at 7,200 per hour.



WHERE IT STORES INFORMATION . . .

These two magnetic drums will hold the balance figures for 50,000 accounts and will temporarily memorize all daily transactions. More permanent storage—with a month's details—will be held on tape.

flow of account statements for ten bank branches in a single working week. To get the required 10-15 lines per sec, a 1,200 rpm cylinder with rows of individual numbers and letters around its surface was designed. As this cylinder turns, coded signals from the tape actuate striking hammers so that all of the same characters that will appear on a single line are printed. Hence only one revolution (1/20 sec) is required for a completed line.

Another problem was to file processed checks according to the order of their information on the storage tape. A magnetic scanning system akin to the input keying device is used. Bundles of checks are pneumatically moved through the sorter, "read", "held" by a mechanical memory device, and passed into appropriate digital subgroup slots. Five passes through the sorter place the group of checks in sequence by account number. The speed and accuracy of this unit should interest the digital design engineer: 10 checks per sec and machine errors of less than 1 in 100,000.

ERMA's most enthusiastic booster is S. Clarke Beise, president of the Bank of America, who claims the new system is "the biggest advance in bank-account bookkeeping in the history of banking". He is anxious to get the prototype model moved to San Jose to handle checking accounts for several Bank of America branches in that area. And he eventually plans to have complete coverage with 37 ERMA machines.

Engineers and scientists at Stanford Research are justifiably proud of their creation. Actual work on the project was done in the Computer Laboratory and the Control Systems Laboratory under the direction of Dr. Jerre D. Noe, who, you'll recall, took time off a few months ago to author CONTROL ENGINEERING's first article in the Basic Digital Series.

. . . and Railroading Schedules Ahead for Nationwide Pulse-Controlled Traffic

Railroading, like banking, is a service industry almost strangled by the paperwork that spells—and can ruin—efficient service. And, like the awakening banks, they are also on the verge of replacing time-honored routine with the efficient concepts and tools of control systems engineering. Some recent actions:

▶ In 1954, Union Pacific applied automatic control, via an analog computer, to a 42-track freight-shuffling yard (reported in the January 1955 CONTROL ENGINEERING, page 29).

▶ In April 1955, railroad systems people met in Chicago to appraise their use of the IBM 705's and Univacs that they had ordered in record numbers (seven delivered, 24 on tap). One highlight: how New York Central kept track of car movement in 28 yards with a 650 magnetic drum computer.

▶ Late last spring official word came from the New Haven of an automatic reservation system involving telegraphed pulse signals (see June 1955 issue, page 16). A few months later brought similar word from the New York Central (October, page 22).

Pieced together, these and other isolated developments suggested a revolution in railroading. But the true potential of this revolution really came to light on Oct. 6 when three railroads linked their pulse-networks in a nationwide reservation system.

Catalyst for the cross-company, cross-country system is the Teleregister Corp. of Stanford, Conn.—the firm

THE KEYSET that will be used by railroad agents identifies train, accommodation, date, and has 8 instruction toggles. . . . AND THE NETWORK ➡ will place keysets in major cities from Boston to Oakland.

BASIC COAST TO COAST ELECTRONIC RESERVATIONS NETWORK

that pioneered the equipment with the help of the New Haven and the New York Central. Splicing the New Haven's New England end with the Central's vast eastern network, and then bringing in the Santa Fe, Teleregister strung automatic reservation and routing from Boston to Los Angeles.

The railroads will benefit from interlocked pulse-reservations as much as the traveling man. Automatic reservation eliminates 22 separate steps for each leg of a trip—and there can be several legs in a cross-country tour. The traveler, in turn, will get immediate confirmation of space, exact departure times, exact pricing, and alternate space, if necessary. And all this can be done 10 min before train time.

Keysets that can handle up to 11 separate types of transactions will be placed by Teleregister at major cities along the routes. When a passenger requests space the agent will insert a coded "destination plate" in his keyset and depress the departure date button. With a flip of the availability switch the remote drum is scanned and lights actuated on the keyset to show the space available. After the space is selected and bought, the agent operates a "sale" button to cancel that space on the memory drum.

Teleregister has broad plans for its system. Circuits already designed will bring in Canada and Mexico and link air to surface carriers. And visionaries in the railroads project even further. They see pulse-coded signals expediting freight as well as passengers from line to line and the movement of goods on rails becoming more of an automatically controlled process and less of an uncontrolled variable.

INSTITUTIONAL DOINGS

British Chemists and Control

Early in October the British Institution of Chemical Engineers and the Society of Instrument Technology got together in London for a rewarding conference on automatic process control. Besides the usual papers on control of specific chemical processes and the economics of control, the meeting included two topics that were eye-openers to many of the chemists in the audience: a paper on the dynamics of process plant, and another linking controllability to chemical plant design. The thoughtful *London Economist* reported this impression of the conference: "In the chemical industry . . . control engineers have their laments. They argue that their traditionally empirical application of instruments and controllers . . . is now hampered by a lack of adequate theoretical foundation. "They feel, too, that the people who design and operate chemical equipment are often insufficiently aware of what really goes on throughout the process . . . and therefore of the characteristics that it will be worthwhile to control." The *Economist* went on to say that "such problems, at the moment, are far more important than questions of economics of control equipment, or trade union reaction to it." And to the *Economist* we say, "Hear! Hear!"

American Chemists and Control

Just a week prior to the special session on control in London, our own Institute of Chemical Engineers gathered for its annual meeting at Lake Placid, N. Y. And while control was not the major topic, a concern parallel to that sensed by the *Economist* pervaded the American conclave. A speaker from industry, Bruce K. Brown, President of Pan-American Southern Corp., recognized the problem when he observed that chemical engineering now requires specialists who are familiar with basic principles and mathematics, including the new techniques of linear programming. Engineering Dean J. C. Elgin of Princeton University amplified this point when he predicted that ". . . by 1975 all efforts to teach engineering art and technology in the university will be abandoned." He saw industry supplying this phase of training, and the schools supplying the basic "science" of engineering which will embrace and transcend most fields of engineering that we know today.

Focusing on FR

Two more steps have just been taken to make the technique of frequency response testing a more definitive tool

"This Is What I Want in a Potentiometer"

1 **Versatility**—A potentiometer to meet a wide field of applications without additional design changes.

2 **Permanent Accuracy**—Resistance element integrally molded within the housing. All leads, taps and terminals firmly encapsulated, permanently locked in place.

3 **Long Life**—Rigid, fixed lead screw to guide contact over resistance element.

4 **Dependability**—A potentiometer that possesses excellent mechanical and electrical stability under extreme environmental conditions.

5 **Absolute Linearity**—A potentiometer with linearity built into it. I don't want to hunt for linearity by trimming.

6 **Specifications**—It must meet my rigid commercial and/or military equipment requirements.

7 **Availability**—I want the model that fits my needs readily available in production quantities.

BORG 900 SERIES MICROPOTS

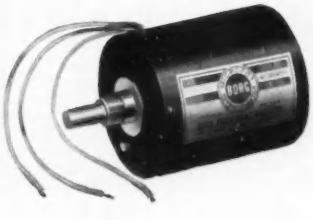
Meet All These Requirements

"It's tops!", that's what design engineers everywhere are saying about the Borg 900 Series Micropots. To meet the tremendous demand Borg has geared production to new high levels assuring you fast delivery of any model in any quantity. All 48 models are available now!

It's no wonder that these pots have had such a tremendous reception for they are truly the "New Standard of Precision Potentiometers". Let us send you engineering data and name of your nearest Borg "Tech-Rep". Write today.

BORG 1100 SERIES MICROPOTS

A precision 10-turn potentiometer that offers your products a price advantage in today's competitive markets. Engineered for easy installation with 9 inch coded leads. Accurate, dependable, long lived.



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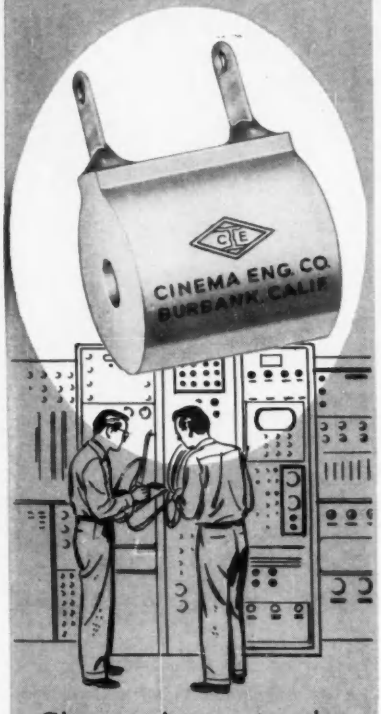
BORG EQUIPMENT DIVISION
THE GEORGE W. BORG CORPORATION
JANESVILLE, WISCONSIN

used in the finest electronic equipment



Cinema Accurate wire wound resistors have seen years of service use in the nation's finest precision equipment. If reliability is your need . . . switch to Cinema resistors.

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CINEMA ENGINEERING CO.
DIVISION AEROVOX CORPORATION
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for the control engineer. In September IRD Dynamic Systems Committee of ASME under Chairman Rufus Oldenburger, Woodward Governor Co., issued a new ASME Standard, No. 107, which describes a standard method of presenting frequency response information. CONTROL ENGINEERING's Bill Vannah, a member of the committee, enthusiastically predicts that the Standard should do much to eliminate the confusion that has resulted when competitive products are compared from variably presented frequency response data.

At the same time, a new subcommittee of ISA Recommended Practices Committee has been set up under Chairman Fred Winterkamp of du Pont, to develop a uniform practice for frequency response techniques. Another ISA activity in this realm is a proposed educational motion picture on frequency response which Dave Boyd, Universal Oil Products, is organizing and hopes to produce in the near future.

The Senate Probes Automation . . .

WASHINGTON, D. C., Oct. 14—The picture below was taken on the first day of a two-week investigation into automation by the economic stabilization subcommittee of the Joint Congressional Economic Committee. A star witness in this first session was Walter P. Reuther, gesticulating president of the CIO and its Auto Workers affiliate. Only one member of the five-man committee turned up for the hearing—Rep. Wright Patman, who sits in the center facing Reuther. Flanking Patman are two advisers to the subcommittee. For a more detailed story on the hearings see *Industry's Pulse*, page 33.

. . . and the Word Gets a Definition

Centralab Div. of Globe-Union, Inc., really picked a "live" topic when it selected this question for one of its recent Electroni-Kwiz contests: "If you were to make like Webster, how would you define the word "automation"?

FOR THE WINNING DEFINITION ➡

2 TWO NEW PRODUCTS JOIN THE LFE FAMILY!

503

LFE MODEL 503

ELECTRONIC DIGITAL MULTITESTER

The 503 — a new type of electronic Multitester — presents display digitally — uses electronic counters.

Unique Model 503 uses three decade columns of neon lights for the indication — gives *absolute* readings — *eliminates* problems of parallax and ambiguity.

Rugged Model 503 is precise — dependable — lightweight.

And—the skill is in the instrument—so almost anyone can use it—confidently—efficiently—in shop or laboratory!

A PREDETERMINED

COUNTER OF HIGH-SPEED VERSATILITY!

The "genius" of the LFE 502 lies in its ability not only to count a predetermined number of impulses, but also to use these pulses for control. So, when you buy the 502, you're buying both a Predetermined Counter *and* a control device in one compact instrument. Automatic sorting and packaging, control of motor speeds or machine tools, generation of precision delays, interval measurements — whatever counting and controlling task you assign the LFE 502, you can depend on this accurate, dependable, high-speed instrument to give you perfect satisfaction.

For specifications and more details about these new instruments, write for our free informative bulletins and the name of the LFE Engineering Representative nearest you. Inquiries on export sales should be addressed to: Andrew S. Szucs, Inc., 50 Broad St., New York 4, N. Y.

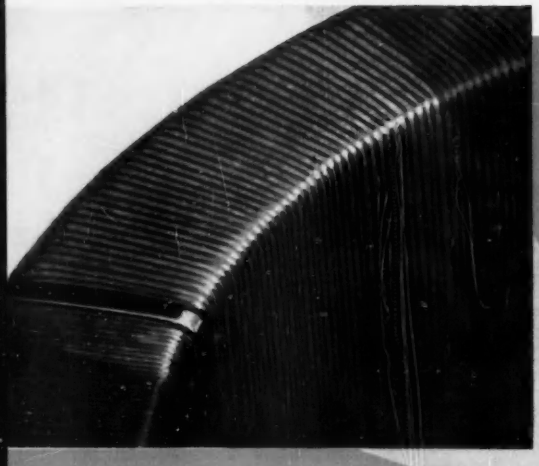
502

LFE

LABORATORY FOR ELECTRONICS, INC.

75 Pitts Street, Boston 14, Mass.

OHMITE® RHEOSTATS HAVE *Smoother Windings!*

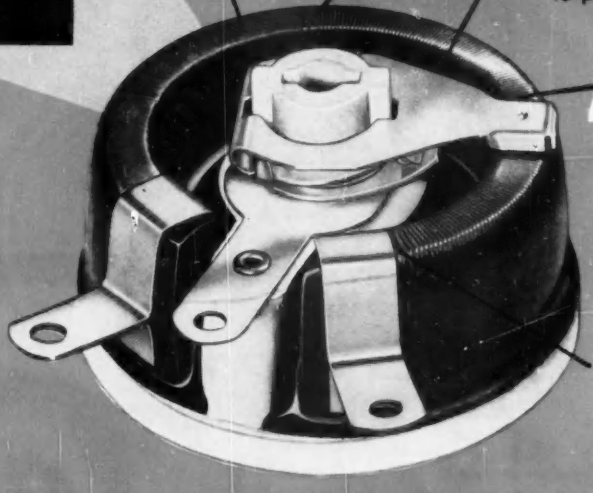


5 REASONS WHY—

1. PRECISION GROUND CORE . . . Cores for fine wire, high resistance units are ground to give a smooth, flat contour for the contact brush.

2. SMOOTH JUNCTIONS where wire sizes change between sections of tapered windings . . . less differential between wire sizes.

3. PERMANENTLY LOCKED WINDINGS . . . Core and windings are bonded together with vitreous enamel to prevent shifting of wire.



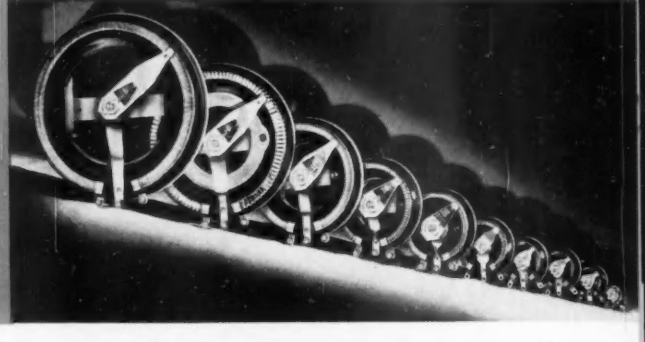
4. UNIFORM WIRE SPACING . . . Ohmite has developed special winding machines to insure uniform spacing and eliminate crossover of adjacent turns on fine wire units.

5. FLUSH TERMINALS . . . Terminals are flush with windings . . . brush glides smoothly from windings to terminal.

See for yourself! Examine an Ohmite Rheostat first hand. Compare its smoother resistance windings. Turn the knob and note how easily and smoothly the contact brush glides over the rheostat windings.

There's less wear on the resistance wire and on the contact brush. The brush makes contact with all of the turns and the resistance varies smoothly and uniformly as the shaft is turned. Every Ohmite Rheostat is *individually tested* on ultrasensitive electronic instruments to assure perfect contact between the winding and the contact brush.

Standardize on Ohmite Rheostats for unsurpassed dependability, smoothness of operation, and long life.



A COMPLETE LINE OF RHEOSTATS

from 25 to 1000 watts. Also available to meet MIL-R-22A requirements in *each* of the 26 type designations.

Write on company letterhead for Catalog and Engineering Manual No. 40.

Be Right with OHMITE®

OHMITE MANUFACTURING COMPANY, 3674 Howard Street, Skokie, Illinois (Suburb of Chicago)

RHEOSTATS • RESISTORS • RELAYS • TAP SWITCHES

THE WINNER: Mustachioed Robert Oakes Jordan, a true blackboard control engineer, got the maximum for his definition of "automation"—a petite 14-D pair of shoes. Officiating is Centralab sales manager, Bob Mueller.

Less than a week after Centralab's ad appeared, the would-be lexicographers responded like swarm of honeybees. A quick look at 50 of the most substantial answers convinced Centralab that "automation" had more definitions than the Brooklyn Dodgers had rooters. And, like the Brooklynites, each answer had character. But after uncanny deliberations by McGraw-Hill judges for Centralab, this entry, from Illinois engineer Robert Oakes Jordan, won the prize:

> **"Automation": those processes which formerly necessitated man's constant attention to operation, that may now be performed on schedule automatically through accurate programming by predetermined systems and pre-set controls."**

However, hard on the heels of Jordan's excellent and precise definition were some other neo-Websters who seemed equally sure of their answer. Some samples:

▶ "Automation is the result of applying system engineering techniques to manufacturing processes so that they can be made to operate automatically"—from a chemical company engineer in the southeast

▶ "The practice of increasing production by decreasing the quantity of manual operations, particularly in the handling of work pieces between machining or other processes"—from a project engineer at a baking equipment company

▶ "The application of the science of automatic control to industrial processes"—from a West Coast consulting engineer

▶ "The assembly of components into a complete unit, by means of automatic machinery with and without direct human aid"—from an ordnance corps engineer in the south

▶ "The control of material in motion with absolutely no physical or human exertion"—from an industrial marketing specialist

▶ "The engineering art of eliminating human supervision and control by designing the functions of measuring, evaluating, and correcting into a process or machine"—from a business machine design engineer

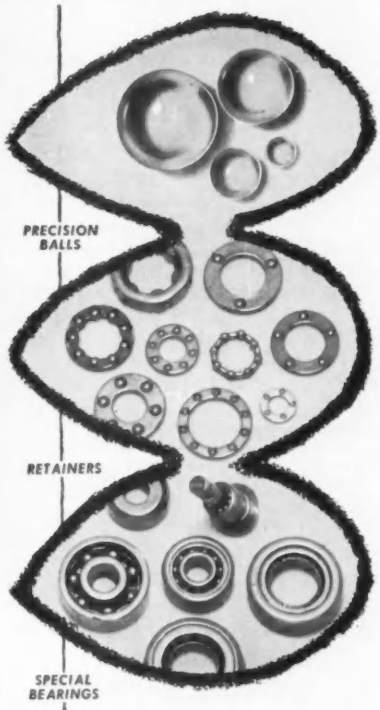
Some of the contestants threw up their hands at the task. Wrote one succinctly from Boston, "Automation is the substitution of mechanical error for human error."

And another from rural Virginia penned this lyrical excuse:

"There's a process that's called
'Automation'
That is swiftly engulfing the Nation;
But if asked to define it,
I'd rather decline it—
Than risk some machine's
abnegation."

Rather than risk some of its readers' abnegation, the editors of CONTROL ENGINEERING will have to go along with the man from Virginia.

LET HARTFORD
carry the load
ON YOUR BEARING REQUIREMENTS



If your product requires precision balls, thrust retainers, or bearings made to your specifications, it will pay you to check with Hartford. And if you are in a hurry we can ship at once on nearly a thousand items.

FREE HARTFORD LITERATURE

Check Items Desired

- ☐ *Hartford Precision Balls*
- ☐ *Hartford Thrust Retainers*
- ☐ *Angular Contact Bearings*
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- ☐ *Versa-Twin Double-row Ball Bearings*
- ☐ *Triple Action Tumbling Barrels*
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Just attach this coupon to your letterhead and please sign your name and position.

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PRECISION BALLS ● BEARINGS

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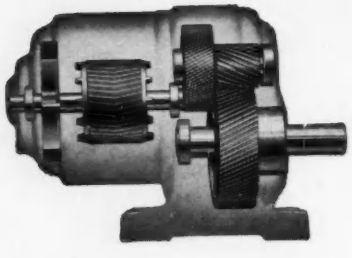
Continuous Flow Fish Processing Aided by Slo-Speed

Automatic, continuous flow processing of fish from boats to freezing units requires drives on our scaling machines, elevators and conveyors that withstand sea water corrosion, are easy to keep clean, and above all, assure dependable trouble-free service. Sterling totally enclosed Slo-Speed drives meet these requirements by providing the geared low speed we need in a single, compact, streamlined unit having a rugged, corrosion resistant, gray iron housing, reports C. Louis Isenberg of Standard Fish Co., Boston.

STERLING SLO-SPEED



OUTSTANDING FEATURES:

Simplified gear system — balanced design — compact — rugged — highly efficient — abundant lubrication — low output shaft — positive oil seals — Herringbone Rotor — protected — streamlined — direct through ventilation — quiet operation — AGMA speeds — extremely long life — every unit will operate in any position.

20-page illustrated catalog... Sterling Speed-Trol, Slo-Speed, Klosd and Klosd-Tite Electric Power Drives. Write for catalog No.205

STERLING ELECTRIC MOTORS

Plants: New York City 51; Chicago 35; Los Angeles 22; Hamilton, Canada; Santiago, Chile
Offices and distributors in all principal cities

WHAT'S NEW

Important Moves by Key People

▶ When **Vincent V. Tivy,** formerly manager of refinery instrument sales for The Foxboro Co., took over as chief application engineer, a broad list of new duties faced him. Among them: coordinating sales engineering with production engineering; new product development; field trials; special sales work involving analysis of automatic control problems; evaluation of instrumentation trends, and service on Foxboro's engineering executive and sales product committees.

▶ Principals in a series of significant appointments by Minneapolis-Honeywell are **C. L. Peterson,** named vice-president and general manager of Brown Instruments Div.; **Jerre Manning,** manager of the Transistor Div. in Minneapolis; and **A. Lachlan Reed,** director of industry-education relations, a new position. Peterson formerly was divisional vice-president, and Manning was general manager of the Marine Equipment Div. Reed joins the company from the office of the U. S. Commissioner in Education.

▶ **Jacob J. Jaeger,** the new vice-president and chief engineer of the Machine Tool Div. of Pratt & Whitney Co., Inc., has been chief engineer of the Machinery Div. since 1954. He joined the company in 1940 as a research engineer and in 1948 became assistant manager of machinery engineering.

▶ Two vice-presidents, **Daniel T. Gunderson** for engineering and production, and **Lloyd E. Schumacher** for sales and customer relations, have been appointed by J. B. Rea Co. At the same time, **Francis A. Oliver** becomes manager of the new Data Storage Devices unit, which will concentrate on development of magnetic storage components. Gunderson comes to Rea from Cook Research Laboratories of Cook Electric Co., Schumacher from Logistics Research, Inc., and Oliver from National Cash Register's Electronic Div.

▶ **Maurice S. Hartley,** Sanborn Co.'s new director of engineering, participated in Great Britain's wartime radar program from the time it was a neophyte in 1939 until his discharge from the Canadian Navy in 1946. He comes to Sanborn from Raytheon Mfg. Co., where he was product manager. Previously he had been with Imperial Oil, Ltd., and Philips Industries, Ltd., both of Canada.

▶ Centralab Div. of Globe-Union, Inc., has elected **Robert L. Wolff** vice-president for engineering and has appointed **W. S. Clark** and **R. C. Anderson** managers, respectively, of

V. V. Tivy

J. J. Jaeger

D. T. Gunderson

M. S. Hartley

R. L. Wolff

Joseph Harrington

the "Badger" and "Keefe" plants.

▶ **Dr. Joseph Harrington,** formerly assistant director of research for United Shoe Machinery Corp., has joined the Mechanical Div. of Arthur D. Little, Inc., consulting industrial research firm. He will concentrate on automatic electronic machinery.

▶ **Dr. Emilie V. Haynsworth,** a former professor of mathematics, has joined the Computation Laboratory of the Applied Mathematics Div. of the National Bureau of Standards. She will code problems for the bureau's SEAC computer and do research in algebraic matrices and determinants.

▶ **Del F. Kahan,** formerly chief design engineer for United Control Corp., has joined Autron Engineering, Inc., as vice-president and chief engineer.

▶ As chief application engineer for American Electronic Mfg., Inc., **Wayne S. Blackman** will supervise sales and application of the company's miniature precision resolvers, servo motors, and synchros. Before joining American Electronic six years ago, Blackman was with Minneapolis-Honeywell and Norden-Ketay.

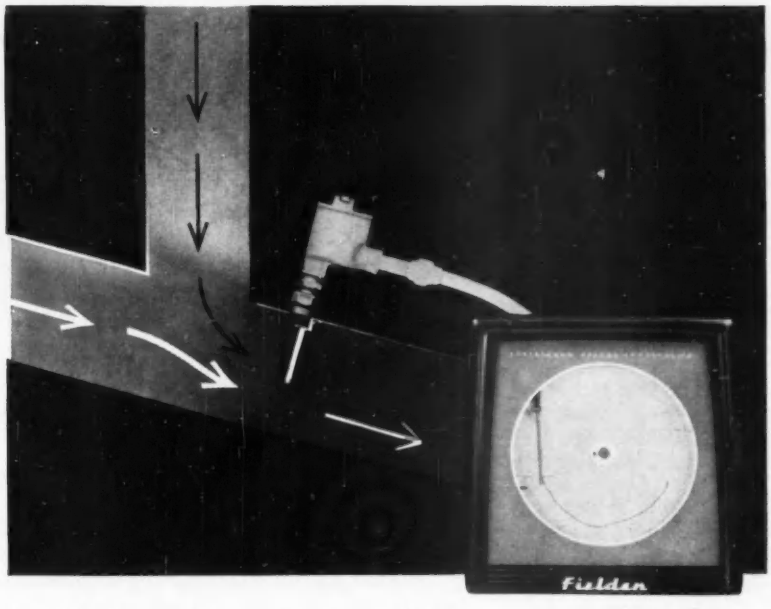
▶ **Devern A. Chubb** will supervise engineering design, research, and development as Abrams Instrument Corp.'s new chief engineer. He was in electronic work in the Naval Research Laboratory before joining Abrams several years ago as project engineer.

▶ **John M. Embree,** who joins Philbrick Researches, Inc., as chief applications engineer, brings with him a handsome background in aircraft and control technology. His past affiliations include Grumman Aircraft Engineering Corp., Kellett Aircraft Corp., Wright Aeronautical Corp., Celanese Corp., Brown Instrument Div. of Minneapolis-Honeywell, United Aircraft Corp., and Chandler-Evans Div. of Niles-Bement-Pond Co.

▶ As liaison engineer for Ford Instrument Div. of Sperry Rand Corp., **Bernard Goldman** will represent Ford on contracts with the U. S. Navy Bureau of Aeronautics. An engineer-journalist, Goldman joined Ford in 1952, along with **Maxwell Bernson,** another skilled technical writer, who has been named supervisor for the preparation of technical military publications.

▶ With **Phillip Herman,** formerly with Thompson Products, Inc., as its supervisor, a new Applied Mathematics Section comes into being in the Technical Services Div. of Jones & Laughlin Steel Corp. Herman, who has been development engineer and statistician for Thompson, heads a section that will facilitate application of advanced mathematics and statistical principles to plant operating data.

Continuous Analysis of Process Streams Now Simplified by Fielden Unit



Engineers in many process plants are now continuously analyzing process streams successfully for composition, purity, or moisture content without the bother of complex, time-consuming laboratory techniques.

The only equipment used for these measurements consists of a Fielden R. F. Capacitance Bridge Recorder-Controller and a single-unit capacitance probe. If the process stream mixture changes its dielectric constant, the capacitance measured at the probe changes accordingly. By continuously measuring product capacitance, the recorder shows the composition of the process stream at all times.

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What Happened to Perkin-Elmer the Day the Flood Struck

If it was still tacked to the company's bulletin board on Monday morning, Oct. 17, the page from the house organ of The Perkin-Elmer Corp. must have hung like a dejected salute to irony. For the page reported the damage, by summer floods, to many of Perkin-Elmer's New England suppliers. These floods had spared Perkin-Elmer, and in its house organ the company had congratulated itself upon its good fortune.

But on this Monday morning, there were three and a half feet of water under the very bulletin board that had carried the happy news. Rains that began on the preceding Friday had swelled the Norwalk River in Connecticut, built it into a raging torrent, and sent it sweeping toward the colonial-style headquarters building and the adjacent plant. Later, rumors put the damage at between $3 and $4 million. This was excessive, but the true estimate was by no means a springboard for joy. It set the loss at between $500,000 and $1 million.

But a company like Perkin-Elmer is successful because its people and its products make it so. The resiliency and toughness of both put in a lot of overtime in the days immediately after the flood. But it was worth it. Some of the evidence:

▶ If proof of the accuracy and reliability of P-E's Tri-Non process stream analyzers was still needed, it surely made itself plain. Two analyzers, shrouded for several days in water, mud, and dampness, were found to function and calibrate perfectly. They were destroyed, of course, along with any other instruments that had come into contact with the water. (See CONTROL ENGINEERING, October 1954, page 42, for an article on the analyzer by Perkin-Elmer's Paul A. Wilks, Jr.)

▶ A spanking new infrared spectrophotometer was readied for delivery just nine days after the heavy rains came.

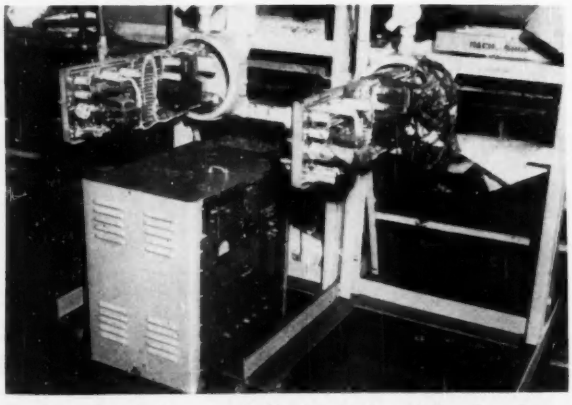
▶ A steady vigil, uninterrupted despite the furious bustle, was maintained over the newly-born P-E vapor fractometer by its operator, Harry Hausdorff.

▶ And somehow, in the frenzied pace of the first day, typhoid shots were administered to every employee.

Many employees' wives pitched into the debris, and it was a mighty welcome sight to see experts handle the mangles, ironing boards, and other apparatus that dried vital records.

In the days that followed, Perkin-Elmer was like the sick farmer whose wheat needs harvesting. Neighboring companies made drying ovens available, removed machines or disassembled them and cleaned them on the spot, reestablished telephone service, and brought in all necessary supplies. And Perkin-Elmer, in what is considered record time, was back in business.

If how it did it was still somewhat of a mystery, President and Board Chairman Richard S. Perkin supplied the best explanation when he growled affectionately, "If you can't get up off the floor after a haymaker, you shouldn't be in the ring."



You're right, that's seaweed clinging to these infrared analyzers. P-E engineers scraped them clean, dried them out, and rewired them. And, when they calibrated perfectly, condemned them.

Harry Hausdorff (background) tends the new vapor fractometer while the cleanup of the sales lab goes on around him. Hausdorff had to fight through debris to get to the valuable instrument.

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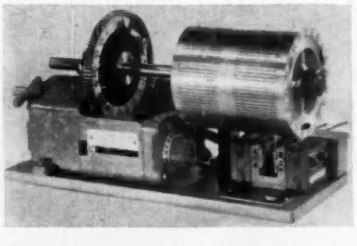

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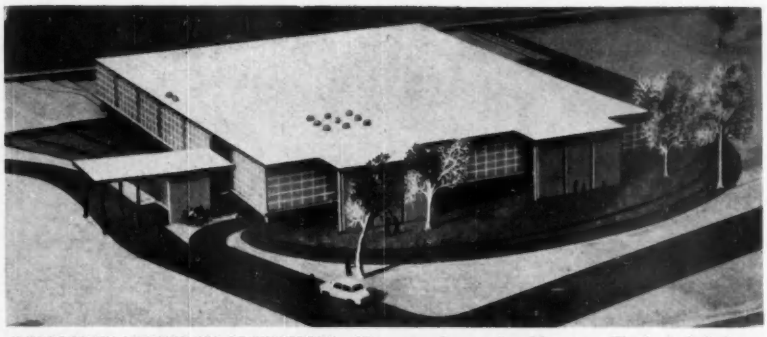
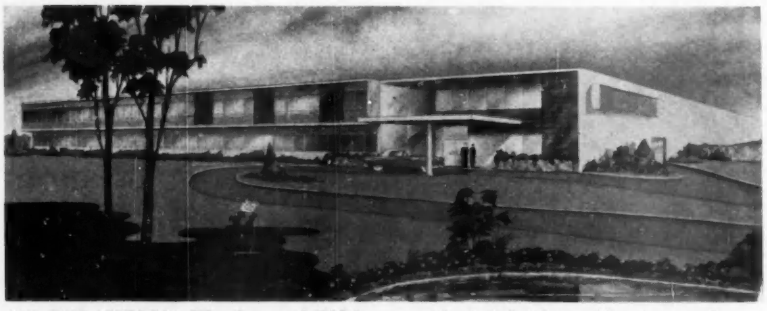


CONSOLIDATION IN HOUSTON. The new home for Houston Technical Laboratories, to be completed next spring, will bring to the Buffalo Speedway all the operations that are now being carried on in scattered locations. Features of the 40,000-sq-ft facility include a skylighted tropical garden and a geophysical instrumentation museum. HTL is a subsidiary of Texas Instruments, Inc.



AH, OKLAHOMA! The farms of Oklahoma, with their bright, golden haze and corn as high as an elephant's eye, have nothing on the cities. Take Tulsa, for instance, where Midwestern Instruments and Midwestern Geophysical Laboratory are completing this million-dollar home (see All Around the Business Loop). The air-conditioned building contains a 26-by-50-ft swimming pool, four bowling alleys, a 400-person cafeteria, and a private dining room for executives.

All Around the Business Loop

▶ The work that's been drawing sidewalk engineers to the corner of 41st and Sheridan in Tulsa, Okla., is bound to be of great interest to a lot of out-of-towners. Center of attraction is the southwest corner, where workmen are putting the finishing touches to the new, million-dollar home of **Midwestern Instruments** and **Midwestern Geophysical Laboratory.** But inside the two-story building, out of sight of the sidewalk observers, changes have taken place that are just as dramatic.

For M. E. Morrow, founder and president of the instrument research and manufacturing company, has moved up to chairman, and his son, G. R. Morrow, has become president. In the eyes of the Morrows, as well as in the eyes of every other person in the plant, this election crowned an impressive chain of accomplishments. One of them was the acquisition of three MIT engineers, whose wartime projects—servo valves, torque motors, and other guided missile apparatus—have become the most important products in the line of Midwestern Instruments.

Among the other links in the Tulsa facility's accomplishment chain: the achievement of a particular level in its production of electronic equipment (nine-tenths of what it is today); incorporation of Midwestern Instruments and its laboratory subsidiary; and completion of the new building, whose 78,000 sq ft are more than three times as much as that available in the corporation's two former buildings together.

▶ Three new divisions have pitched into the increased work load of **G. M. Giannini's** airborne operations. The new divisions, for **Gyros, Systems,** and **Transducers,** are actually subdivisions of Giannini's former **Airborne Instrument Div.** D. R. Gero, recently named vice-president and airborne operations manager, will be overall supervisor.

▶ British and continental airframe

manufacturers soon will find in Brentford, England, a more accessible source for the aircraft hydraulic components made by **Vickers, Inc.** These components have been added to the production line at **Sperry Gyroscope Co., Ltd.**, well-known on the isles for its airborne instruments and, like Vickers, a division of **Sperry Rand Corp.** Sperry already is delivering one accessory and expects to get rolling in earnest by late 1956.

▶ On the strength of its new name, which is **Consolidated Electrodynamics Corp., Consolidated Engineering Corp.** expects to be able to qualify in New York, where "engineering" has been construed as a misnomer, and in Pennsylvania, where a conflict over similar company names spelled its exclusion. The change, however, was not made in an effort to expand activities. According to Consolidated's President Philip S. Fogg, "engineering" does not adequately describe the company's business and is apt to have, at certain times, a narrow connotation, and at other times, a wrong one.

▶ In a new electronic research center on a three-acre site leased for 99 years from Leland Stanford Junior College, **Admiral Corp.** will expand its **Advanced Development Section** and press its work on guided missiles, radar systems, air navigation, nuclear radiation measurement, direction finding, and communications. Robert M. Jones will head the contingent of engineers that will move to the new laboratory, in Stanford Industrial Park, at the end of the year.

▶ **Metrotype Corp.**, a recent acquisition of **The Hays Corp.**, left Summit, Ill., recently for Michigan City, Ind., where it will be next door to its new parent.

▶ **International Resistance Corp.** is throwing a brand new roof over three of its subsidiaries: **Hycor Co., IRCal Industries,** and **Emec, Inc.** The one-story building, in Sylmar, Calif., will also house IRC's West Coast warehouse. About 200 employees will move into the 26,000 sq-ft facility early next year.

▶ Recent acquisitions: **Tartex Electronics** (miniature and sub-miniature transformers for aircraft) by **New York Transformer Co.** — Tartak's name changed to **NYT Electronics; Computer-Measurements Div.** of **Detectron Corp.** by **RC Controls Corp.; Econo Products Co.** (hot-water heating instruments) by **Viking Instruments, Inc.; Kaye Development Co.** (electronic color evaluation instruments) by **Atomic Instrument Co.;** and **Commercial Research Laboratories, Inc.** (Cox Instruments, flowmeters, and other scientific apparatus) by **The George L. Nankervis Co.**

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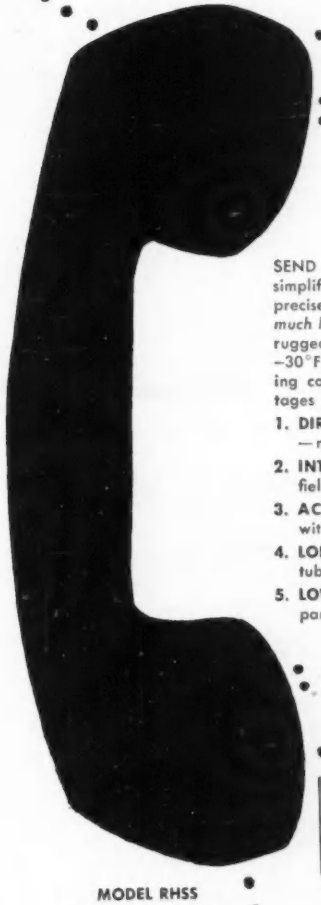

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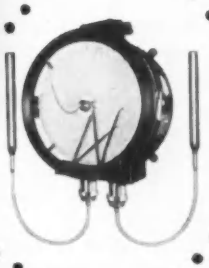

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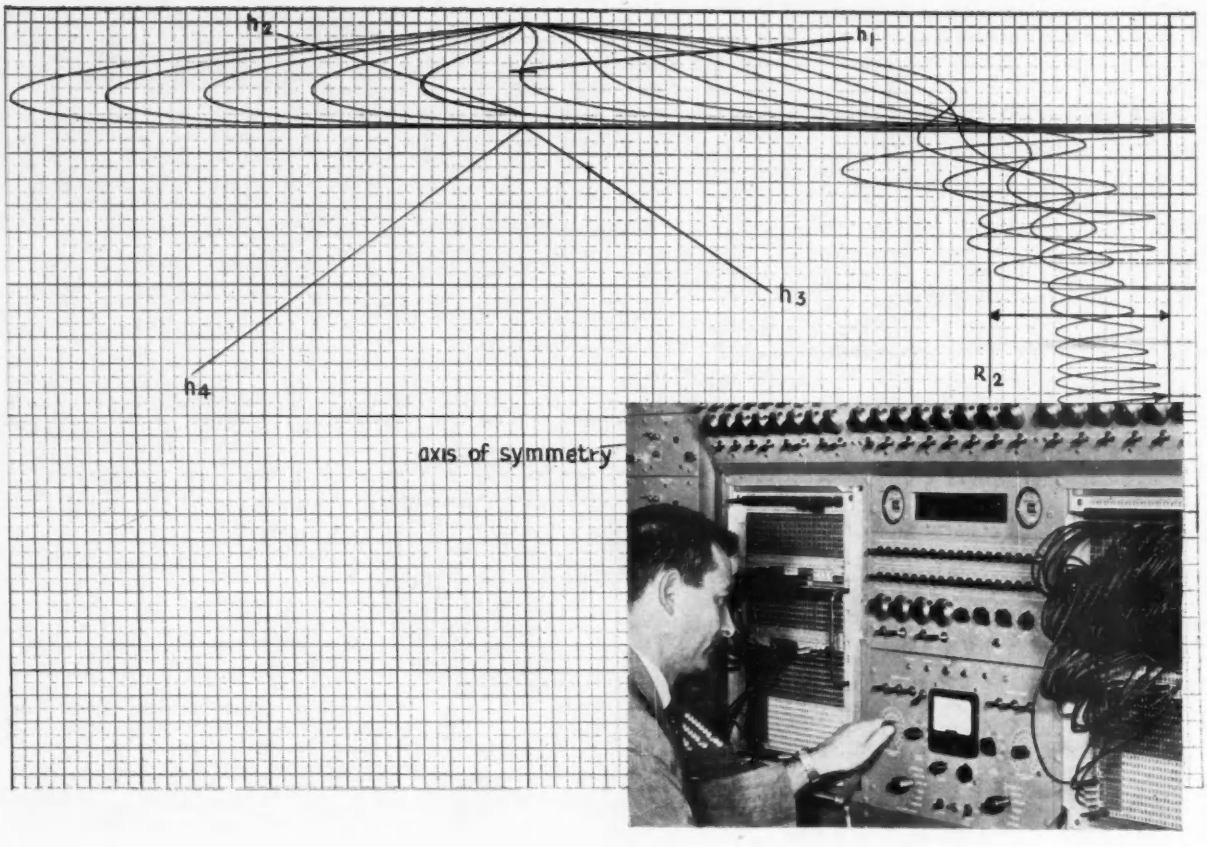

Application in solid state physics . . . a demonstration of the versatility of EAI Computers . . .

One of the complex problems faced by a certain manufacturer, who was concerned with an industrial method of purifying silicon rods, was to determine the physical conditions which lead to stable liquid zones when the rods were subjected to concentrated heat, as well as the shapes of the hanging liquid drops.

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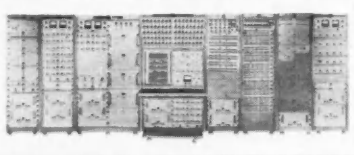
Information also will be furnished on request concerning EAI's Computation Center at Princeton, New Jersey, where the use of Precision Analog Computing Equipment may be obtained on a time-rental basis.

EXPANDED 16-31R ANALOG COMPUTER



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Congress Lends One Ear to Automation

Goaded by Walter Reuther's skillful campaign to make the word symbolic of job insecurity (see *Pulse*, February and June, 1955), Congress finally had its full-dress inquiry into the "broad economic and social implications of automation". The hearings, conducted by Rep. Wright Patman's Economic Stabilization subcommittee, ran two weeks—Oct. 14-28—and resounded with carefully prepared testimony by six union executives, 10 industry spokesmen, and eight "neutral" observers from government bureaus and institutes.

Automating in the 4-day week

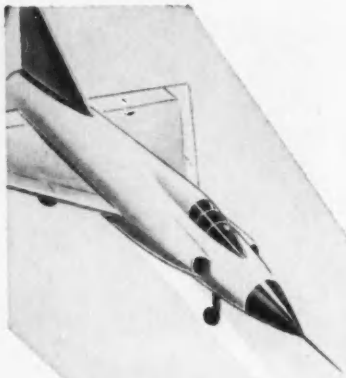
Most loquacious in the parade of labor leaders was redhead Reuther himself. "Labor," he amiably insisted, "welcomes the arrival of automation." But then he went on to urge a "cushion" to keep workers on the payroll when automation spreads: a "gradual reduction" of the work week from 40 to 35 and finally 30 hours. And on this basis a flat prediction that the 32-hour, four-day work week will be with us in ten years.

Industry speakers departed from prepared texts to level some sharp lances against Reuther's convincing arguments. Robert Tait of General Dynamics dramatically intoned that "automation is the only conceivable answer to a *probable labor shortage*" in the years ahead. And Sylvania Electric's colorful Don Mitchell fumed over Reuther's claim that profits from automation rarely reach the consumer. He described the costly scrapping that is saved by automatic techniques in electronic production, then cracked, "Machines can't think—but they're not careless."

Which paper do you read?

Both sides of the story were convincingly told. But when figures were cited on the actual effect of automation on jobs, confusion took the reins over clarity. Communication Workers' Joe Beirne, for example, reeled off a telephone industry employment slippage of 1.6 per cent each year and predicted 100,000 jobs could be lost by 1965. But General Mills' Dr. Cledo Brunetti firmly held that dial equipment had meant a three-fourths increase in operators over the past 10 years.

Government spokesmen hardly cleared the air. Just when labor and management had agreed that automation *does* mean zooming worker productivity, Labor Secretary James Mitchell's calm release of post-war productivity figures showed that average



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manufacturing output per man-hour had increased little more than 3 per cent a year—about the same rate as during the period following World War I. But the full story wasn't there. Mitchell's figures only ran up to 1953. According to McGraw-Hill's economics department, man-hour productivity may have surged to a much more impressive 5 per cent in the past two years.

While most of the inquiry was focused on assembly-line production, one "sleeper" witness cast a new note into the proceedings by reporting on "an industry that was automated before automation was invented". The man: bald, stubby Otto Pragan, research director of AFL Chemical Workers.

Pragan did not parrot other labor witnesses. Instead he showed the effect of automatic control on the type of worker in his industry. In '47, he said, there were three production men to each nonproduction worker. Today, although jobs have grown in number, this ratio is two to one. "The fault does not lie with automation as such, but with our inability to adjust our economic thinking to new levels of technological development."

Pragan's pegging of automation as a technological rather than a socio-economic problem was pretty much lost on Congress—because Congress simply neglected to be there to hear it. Only one member (Chairman Patman) of the five-man subcommittee showed up for the hearings. Even the gallery, usually crammed at probe-time, had only a desultory sprinkling of spectators.

A deflated political football

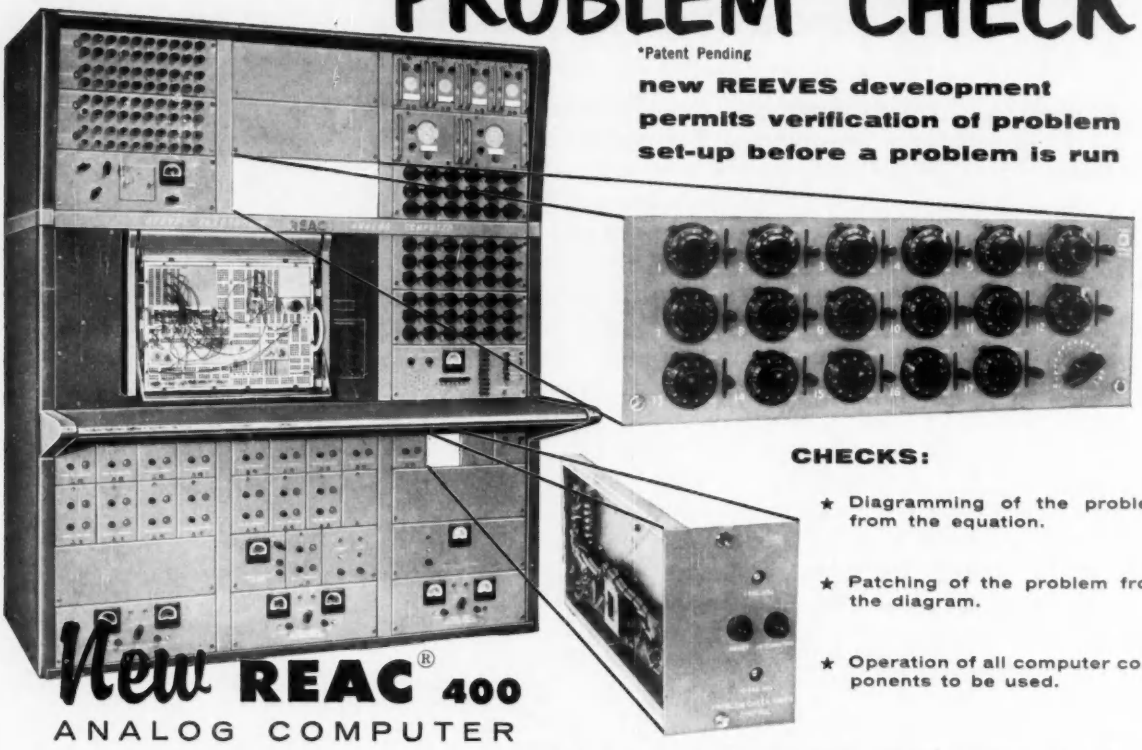
Why has "automation" suddenly become a deflated political football? The reason is obvious: how can job insecurity be a theme when employment is hitting a record high and paychecks are getting fatter?

Perhaps the neatest swan-song to the hub-bub was provided in Rep. Patman's answer to a newsman's query as to whether his group planned any legislation to cope with automation. "No," faltered Patman, "we don't know enough about it, it hasn't developed enough."

PROBLEM CHECK*

*Patent Pending

new REEVES development permits verification of problem set-up before a problem is run



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Prepatch boards are, of course, prepared away from the machine. "Problem Check" means that only an absolute minimum of time is required on the machine to check the problem set-up in its entirety. A great deal of expensive checking and cross-checking while the problem is on the machine is thereby eliminated.

"Problem Check" is a new method developed by Reeves to verify analog computer circuits **without disturbing the problem set-up.** Checking is done directly from the equation **before** the problem is run, and the operation of every computing element is checked. Further, if the output of any computing element is not correct, the location of the difficulty is indicated, and the trouble can be quickly and easily found. After "Problem Check," runs may be taken on the machine with assurance that the set-up is correct and that the machine is functioning properly.

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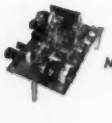
Precision Floated GYROS

Precision RESOLVERS and PHASE SHIFTERS



SERVO MECHANICAL PARTS

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Control
ENGINEERING
DECEMBER 1955

Design by Routine– but Consider the Fundamentals

Four "Feedback Letters" received this month clearly describe the growing professional needs of our field. Two of them are from Gulf Coast readers seeking correspondence or evening extension courses in the technology of control system engineering. They typify many similar requests that have come in over the months from widely scattered plants and industries.

The other two letters, from author J. E. Kadish and a critic, discuss the benefits and pitfalls of following routines in control system design. The critic argues that the system designer must be able to construct complete mathematical design models from basic physical laws. But the rebuttal contends that design of familiar systems can be set up in orderly, straightforward steps to make persons of lesser experience more useful to their engineering group.

Both debaters are right. The engineer pondering new control problems must be capable of unique approaches in analysis and design. University graduates trained in the formal skills of control engineering steadily add to the cadre of engineers who are able to handle the necessary mathematical tools. But these graduates are too few in number – they hardly meet the demand for their services in industrial control, let alone military systems engineering.

Fortunately, the limited number of properly equipped control engineers is strongly supported by "volunteers from design, production, and process engineering," as our October *Industry's Pulse* reported. The two correspondents from the Gulf Coast are such "volunteers"—and to this group we will continue to direct articles. Review and primer articles will teach the application of mathematical analysis to typical problems. Others will describe the routine steps in solving a specific problem, and then demonstrate the routine with numerical examples that include characteristics of specific products on the market. As in the past, new techniques of analysis and design will balance the editorial diet. With this blending of routines with creative analyses we hope to convert the "volunteers" to regulars in 1956.

THE EDITORS

Automation Creates Jobs For Workers With Skills

There is new and reassuring information for those who fear that "automation" – the control of machines by machines – will mean fewer job opportunities. It comes from a special survey of 1,574 companies in metalworking industries recently completed by AMERICAN MACHINIST, a McGraw-Hill publication. More than one-fifth of the companies reported that they already have automatic loading, transfer or assembly machinery in operation. In these companies as a whole there has been a net increase in total employment since this machinery was installed.

According to the AMERICAN MACHINIST survey, of these companies with actual experience in automation

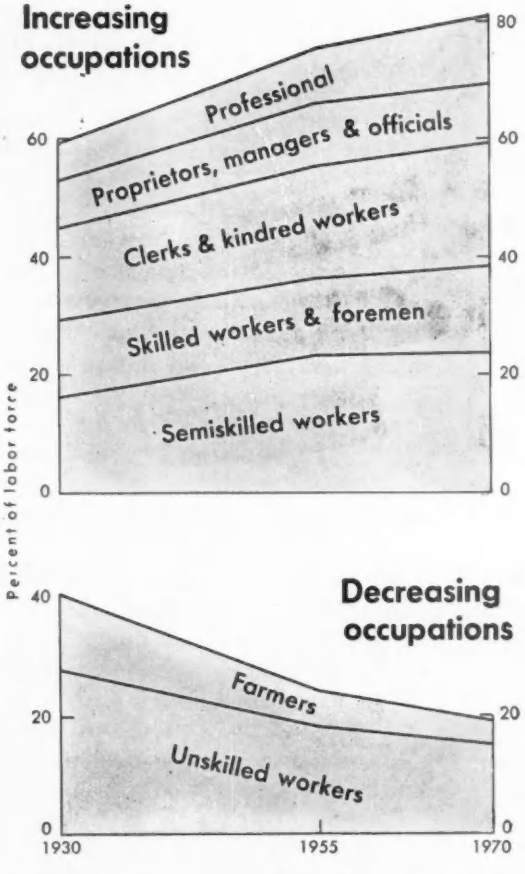
- 26% reported increases in employment averaging 21%
- 51% reported no change in total employment
- 23% reported decreases in employment averaging 16%

More Jobs for the Skilled

Of greater significance, however, is the response by 40% of these companies that they required more skilled maintenance men and by 21% of the companies that they had increased their engineering staffs. This indicates that automation is strengthening a trend already evident in the United States, a trend of expanding opportunity for those with industrial and professional skills and, relatively, of contracting opportunity for the unskilled.

The following chart shows how strong this trend has been over the past 25 years and how strong it may be expected to be over the next 15 years.

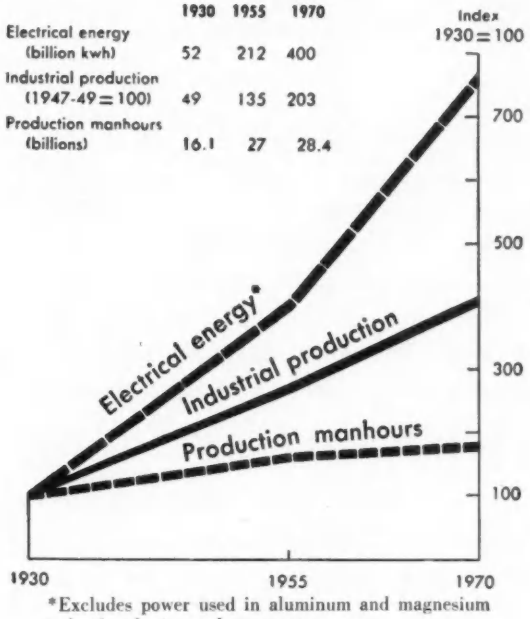
There has been a sharp decline in the percentage of unskilled workers in the nation's labor force and a corresponding increase in the percentage of those with varying degrees of skill.



It is possible, of course, to cite cases of individuals and groups that do not conform to the charted trends. Farmers, for example, are becoming at the same time more skilled and less numerous. But this does not upset the broad proposition that opportunities are increasing for those who have skills.

Power and Production

Much of the basic explanation for the relative expansion of opportunities for those with industrial and professional skills lies in the increasing use of power-driven machinery. This has made possible a vastly greater increase in manufacturing production than in the manhours of human labor devoted to it. The following chart shows the relative increases in electrical energy and manhours of labor used in manufacturing since 1930 and the rise in industrial production.

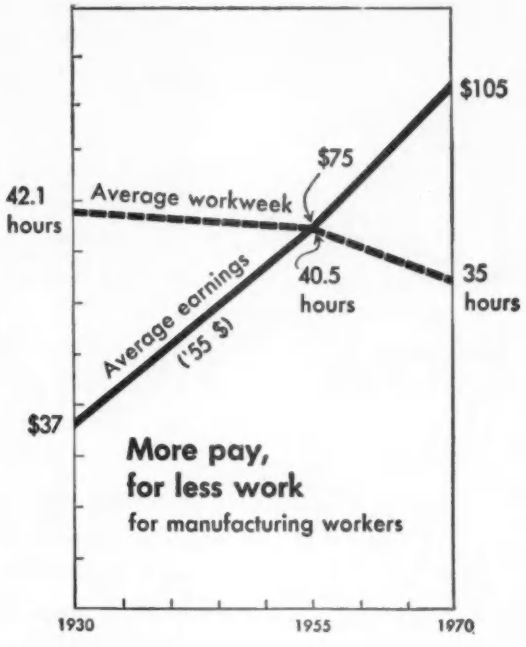


*Excludes power used in aluminum and magnesium reduction, both very heavy power users.

Power-driven machines have reduced the amount of human energy required for physical labor, but they have increased the need for skillful handling and maintenance. As the AMERICAN MACHINIST survey demonstrates, the same is true of automatically controlled machinery.

Higher Wages, More Leisure

The rising average wage of American industrial workers and the decline in hours per week that they must work reflect directly the extent to which the increase in industrial production has outstripped the manhours devoted to it. The final chart shows the increase in weekly wages (in dollars of constant purchasing power) and the decrease in the average workweek in manufacturing since 1930. It also shows the changes that may come in the next 15 years if present trends continue.



There are some who would slow what an earlier editorial in this series characterized as "the continuing process of taking dull and laborious work off the backs and minds of men and transferring it to machines operating in large batteries under automatic control." In doing so, they might make the world safer for those with no skill. The far more constructive course is to welcome the expanding opportunities now being provided and be sure that the nation's young people, who are now starting another school year, are prepared to take advantage of them.

This message is one of a series prepared by the McGraw-Hill Department of Economics to help increase public knowledge and understanding of important nationwide developments that are of particular concern to the business and professional community served by our industrial and technical publications.

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Donald C McGraw

PRESIDENT

McGRAW-HILL PUBLISHING COMPANY, INC.

Data Processing Systems: How They Are Used

This is the introduction to a series of fourteen articles covering the selection and application of data processing equipment and systems. The scope of this Series, while complementary to, is distinctly different from, the Basic Digital Series, which will run concurrently. The prime concern of the Application Series is how the equipment is used, rather than how it works. Subsequent articles will cover programming, system design, and equipment, in three areas: 1) solving scientific problems; 2) handling business data; 3) controlling a process.

EUGENE M. GRABBE, The Ramo-Wooldridge Corp.

Electronic digital computers are probably the most versatile general-purpose tools ever devised by man. With their ability to internally store programs of instructions for long and complex operations, their future in both engineering and business is almost unlimited. But before digital computers can begin to justify these expectations, the practical problems of cost and operating experience must be solved. At present, experience is being accumulated and new designs evaluated.

FROM PAST TO PRESENT

Digital machines' history reaches back to 1801. In that year, Jacquard applied punched cards to the control of a loom for the first application of automatic digital process control. About 50 years later, Babbage proposed punched-card input for his analytical engine, and 100 years after Jacquard, Hollerith of the U. S. Bureau of Census developed the first punched-card machine for computing type operation. These and other milestones in digital computer history are listed in Table I.

Although the first electronic computer is scarcely ten years old, Professor Aiken of Harvard estimates that $100 million has been spent on development. The results have been some excellent high-speed scientific computers. During this period, according to Professor Forrester, head of the MIT Digital Computer Laboratory, computer speed has increased 100,000 times, and storage capacity and reliability 100 times, Table II. But further improvements will come more slowly. Speed, storage, and reliability have reached a stage where there will be some settling down and broadening of computer applications while operational experience is gained.

The dollar volume growth of the digital computer field has been phenomenal. In 1940 this market did not exist. In 1953, the volume was $25 million and Stanford Research Institute estimates that by 1960 it will be one-half billion or more. Although the market for control instruments is also growing rapidly, it seems that by 1960 the computer dollar volume will be four times that of instruments.

Electronic digital computers, at first exclusively used to solve scientific problems, are assuming importance in two other application areas: business data handling and process (real time) control. (See *Data Processing Systems: How They Function*, CONTROL ENGINEERING, October 1955.) The degree of development of these application areas follows about the same order: scientific, business, and control. Users and manufacturers are gaining operational experience with electronic business machines and are still experimenting with the preliminary models of digital control devices.

TABLE I MILESTONES IN COMPUTER HISTORY

DATE	ORIGINATOR	MACHINE	REMARKS
Before 1200	China and Near East	ABACUS	Used by merchants for business.
1642	Pascal	ADDING MACHINE	Successfully applied to tax collection problem in France.
1673	Leibnitz	CALCULATOR	Used in his father's mercantile business. Could perform four basic arithmetic operations, but was not dependable.
1801	Jacquard	PUNCHED CARD	Punched-card loom control for weaving figured fabrics.
1820	Thomas	DESK CALCULATOR	Same principle as Leibnitz, but reliable. Improved models used for next hundred years.
1822	Babbage	DIFFERENCE ENGINE	For calculating mathematical tables. Not completed.
1833	Babbage	ANALYTICAL ENGINE	Programmed automatic computer including decision functions. Punched-card input. Not completed.
1838	Morse	PUNCHED TAPE	Telegraphic communication.
1886	Hollerith	PUNCHED CARD MACHINE	Used by U. S. Bureau of Census for sorting and tabulating data.
1937-44	Aiken	MARK I	First general-purpose automatic digital computer. Electro-mechanical operation. Built by IBM.
1939-45	Eckert & Mauchly	ENIAC	First general-purpose electronic digital computer. 18,000 tubes.
1946-52	U. of Pennsylvania	EDVAC	First computer with internally stored program.
1951	Remington Rand	UNIVAC	First alphanumeric machine.

TABLE II TEN YEARS OF IMPROVEMENT

MACHINE	SEQUENCE CONTROL	ARITHMETIC SPEED (millisec) *				MAXIMUM STORAGE CAPACITY	TYPE
		+	×	÷	compare		
MARK I	Punched Paper Tape	300	7,000	60,000	—	1,728 decimal digits	Mechanical counters
ENIAC	Plugboard or Punched Cards	0.2	0.2	2.8	—	200 decimal digits	Tube registers
EDVAC	Internal Storage	0.846	2.85	2.9	0.696	45,000 binary digits	Mercury delay line
UNIVAC I	Internal Storage	0.525	2.15	3.89	0.365	12,000 characters 11 x 10^6 characters	Mercury delay lines 10 tapes
IBM705	Internal Storage	0.204	0.799	4.82	0.204	20,000 characters 1.8 x 10^6 characters 5 x 10^9 characters	Magnetic cores 30 Drums 100 Tapes

As shown in Table III, equipment requirements are different for the three fields. This suggests a natural division for examining the present status and future horizons of electronic digital computers.

Scientific and Engineering Computers

The modern high-speed computers, such as the Univac and IBM 704, and many smaller machines (IBM 650 and ElectroData Datatron), were developed primarily as scientific computers. The first electronic machine, the ENIAC, had no internal memory other than vacuum tube registers, while the modern machines have high-speed magnetic-core storage of the order of 10^5 bits.

The original scientific computers were excellent for extensive computation that involved little input and output data. But as internal memories have grown, so has the variety of problems that can be handled by stored-program computers. And since scientific calculations often require multiplication and division, manufacturers have concentrated on machines that can rapidly perform these operations too.

In planning for the future, the National Bureau of Standards group under Dr. S. N. Alexander has found that some scientific problems require machine characteristics that are usually thought of in connection with business data problems, such as very large internal storage, and sorting and merging operations. It may be that the differences between scientific and business-data machines are only temporary.

Indeed, many data processors are being used for both scientific and business applications. For example, a steel company's business installation estimates the cost of steel bridge structures. A job that usually takes several months is reduced to a few days, and the results are more accurate.

In the engineering field, computers are designing products ranging from transformers to jet engines. In many cases it is possible to by-pass model building by computing design parameters. Take the case of designing an electric power transformer, where about 10,000 operations are required to describe the process. Up to 20 computer reiterations with varied parameters might be required, corresponding to 200,000 program steps, before the design specifications are satisfied. The need for high speed is apparent. But large savings also evolve when many trial models no longer are necessary.

Problems such as sales forecasting have yet to be formulated. These may require large storage of census data, sorting, and tabulating. Will they be scientific or business problems?

The future holds many possibilities, especially in computer design. There are very few computers that have fully exploited the possibilities of equipment and circuit simplification through the use of Boolean algebra in logical design. From this point of view, practically all equipment in use or on order is obsolete. While machines are reliable and operate satisfactorily, neither they nor their components are representative of the latest technological know-how. In general, the West Coast leads the east in logical design. And by the time machines incorporate the current logical design techniques, the logician will still be a step ahead of them in his theories.

Two of the deterrents to rapid progress are the cost and time involved in designing and producing a digital computer. Early computer design found expression in the "von Neumann constant"—at *any time*, the completion date is always a fixed

TABLE III **HOW COMPUTER REQUIREMENTS VARY**

	SCIENTIFIC	BUSINESS	REAL-TIME CONTROL
Input and output	Small	Large	Small, multi-channel
Computing speed	Very high (microseconds)	High (milliseconds)	Low to high (depends on system time constants)
Total storage	Medium, about 10^6 bits	High about 10^9 characters	Low to medium, about 10^5 bits
Number of logical decisions	Medium	Very large	Small
Program size	Large, about 1,000 instructions	Very large, up to 10,000 instructions	Small
Sorting	Occasional	Frequent	Never
Number of machines in operation	100 — 200	Less than 100	Few

THE MOST USEFUL DEVELOPMENTS HAVE BEEN MAGNETIC DEVICES

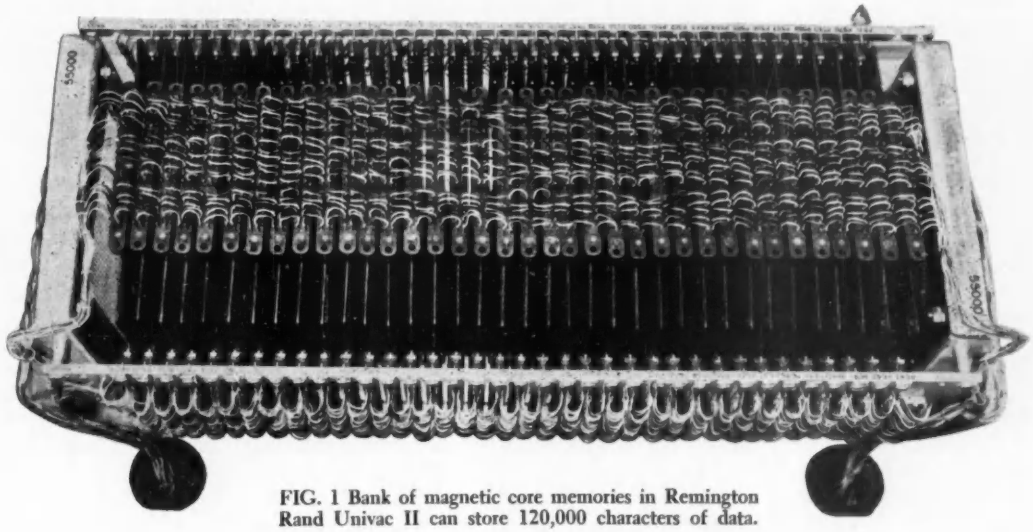


FIG. 1 Bank of magnetic core memories in Remington Rand Univac II can store 120,000 characters of data.

period away. However, there are many new components in the offing that will affect the design and probably the cost of future machines. Magnetic cores, transistors, and other semi-conductor devices, if combined with current logical design techniques, will yield superior machines.

In modern computers, the input and output equipment is less reliable than the computer proper. More basic work is needed in this area. Storage devices, too, have lagged in design and construction, and are still one of the most expensive parts of a computer. The most useful developments have been magnetic devices—drums, tapes, and cores, Figure 1. But the ultimate storage element may be quite different from anything today. Developments in semi-conductors and dielectrics hold great promise.

BUSINESS DATA PROCESSORS

Modern business data processors are essentially scientific computers with special features that make them useful for business problems. These problems are characterized by large amounts of data and frequent input and output. Payroll, customer billing, and inventory control are typical examples. Manipulating this data requires large storage capacity, frequent sorting and decisions or branch routine operations, and sequencing programs that may involve up to 50,000 instructions. Future progress will depend on the design of business data processors for business use and on revamped business procedures. These must go hand in hand. A systems approach is required that applies business and scientific talent to the complex structure of men, materials, equipment, and procedures.

Designers of business machines have been hard-pressed to match the speed of the input-output equipment to the internal computing speed. Again, basic work is required to relieve the severe buffering problems in business equipment. And although the most common business operations are addition, subtraction, and decision making, fast multiplication is desirable since most users tend to apply their business data processors to scientific-type computations. As the solution of clerical problems becomes commonplace, machines will be used for such complex computations as long-range planning, plant design and location, and for making market analysis.

One interesting concept is the use of several small machines rather than one large installation. Another is the use of special-purpose equipment, such as "File Maintenance" machines for sorting operations, and the ERMA, Bank of America machine, for check bookkeeping, Figure 2.

Relatively few companies at present manufacture business data processors. However, there is plenty of room for new blood, and radical advances in thinking could break the field wide open, since it is increasingly clear that available equipment is lacking in many respects. Sorting is slow and expensive, and large-capacity random-access storage is required.

Even though available equipment leaves much to be desired, it can still save money and provide experience. Better machine designs are partly based on past operating experience, and it is up to business to take the lead in setting specifications for the equipment of the future. But business has been slow to adopt these new tools, and the first applications were in government agencies. Two Univacs

at the Bureau of Census will bear the brunt of the 1955 Census of Business and Manufacturing. The normal two-year task of tabulating and compiling will be done in nine months.

The problems of applying electronic data processing to the office are not simple, since they involve overturning antiquated accounting and business procedures. It may take years to change the traditional methods and habits. Take the case of the Court of Exchequer in Great Britain. According to Charles Dickens, this venerable body used the old English tally-stick system of keeping accounts on notched sticks until early in the Nineteenth century (Robinson Crusoe also used this approach). After years of hedging, this antiquated method was finally abolished in 1826 in favor of pen and paper, and it took another eight years to get rid of the accumulated tally sticks. Those who were put in charge of burning these "worm-eaten bits of wood" accidentally set fire to the House of Lords and the neighboring House of Commons. Both burned to the ground. There's a lesson in this for modern business. Do not cling tenaciously to outmoded methods, equipment, and stacks of records that are no longer necessary to run a business.

Many businesses planning data-processor installations are faced with the problems of assembling staffs, planning applications, and preparing instructions (programming). Military experience has shown that these problems can best be solved by teamwork between technical and procedures personnel. The speed with which business can make effective use of the new tools is proportional to its ability to assimilate technical personnel and know-how into business operations. Decisions must be based on sound information and not on intuition. Evaluation of methods of minimizing total information, maximizing information content, setting goals, time phasing, and accuracy all require logical scrutiny and scientific analysis. Mathematical models will be used extensively, and management will lean heavily on Operations Research teams.

Advances in "Automatic Programming", by which the computer constructs and assembles programs, will be a boon. This technique greatly reduces both the man-hours required to program a problem, and the technical skill required of the programmer. In addition, devices that code information in "common language" at the point of origin are sorely needed. These would avoid transcription to cards or punched tape before going to magnetic tape and the computer. Standardization between manufacturers would also help: one machine could communicate with another without expensive code-transformers.

The greatest benefit will come from integrating the office automatic data handling facilities with those of the automatic factory, since basically, information handling in a manufacturing industry concerns control of production, sales, and inventory.

COMPUTER KEEPS TRACK OF CHECKS

FIG. 2. Travelers check scanner developed by Stanford Research for Bank of America's new check bookkeeping system.

PROCESS CONTROL SYSTEMS

In real time control applications, the computer is an integral part of a control system. It receives data from the process, computes, and delivers control signals on a time scale consistent with the stable operation of the process. Examples are continuous flow manufacturing processes, aircraft flight control, and many simulation problems. Computing elements are not new to process control instruments, but usually the computation involves one variable in time. When problems become complicated, when variables are interdependent, or when high control speeds are essential, it may pay to separate the computer from the instrumentation.

Analog computers have been applied increasingly to control of industrial processes since the war, while the digital machine is a newcomer. But it appears that digital computing techniques can compete successfully with analog methods where digital advantages in flexibility, programming, and accuracy are important. Analog-to-digital converters are required, though, since control variables are usually analog in nature, Figure 3.

Digital computers as integral parts of industrial control systems are few and far between. The military has led in this field as a result of the demands of increasingly severe military specifications in accuracy and control, and the availability of government funds to finance developments. Complicated military weapons systems are ideal for computer control, since they can be readily analyzed; for example, missile and aircraft control involves the laws of

motion. Time-sharing for multiple modes of control and auxiliary computations is also possible. Small airborne digital computers have been used to automatically control aircraft flight. (See *Flight Control and the Digital Computer*, CONTROL ENGINEERING, October 1955.) New techniques and components, resulting from continued military support, will slowly filter into the industrial picture.

Before a computer can control a process, the dynamics of the process must be understood. At the present, the flow of liquids in distillation columns and similar apparatus evades rigorous mathematical treatment, and high-speed chemical reactions involving catalysts are even more complex. But experimental and analytical work now in progress will lead to a better understanding of process dynamics. (See *Determine System Dynamics—Without Upset*, CONTROL ENGINEERING, June 1955.)

Contemporary control instruments apply control on the basis of past information rather than on prediction. To predict the future implies a clear understanding of a system. Then high-speed computers can anticipate and control rapidly changing processes. Even operator "judgment" based on past experience can be programmed for a computer; or it may be possible to use computers as learning machines to accumulate and evaluate past experience for future control.

Computers are being used in the laboratory, in the design of processes, and in the digital logging of operating variables. These are but one step from process control. Indeed, many instruments that were previously considered laboratory devices are now available as in-plant process control units. An example is the mass spectrometer.

Computers are commonly thought of as fine for repetitive operations, but no good when nonrepetitive operations are involved. Note, however, that in business applications, the largest savings appear when the computer is programmed to handle exceptions. These exceptions could not be handled by earlier machines. Similar arguments will apply to process control.

Initially, the general-purpose digital computer may be too large for many process control applications, although on a time-sharing basis it may later prove economical. Special-purpose computers with reduced capabilities will fill this need. Digital differential analyzers and combined digital-analog machines are possibilities. Reliability and simplicity will be the outstanding characteristics. Digitizing of analog variables should be accomplished as early as possible in a process. Magnetic amplifiers and transistors will be widely used.

Many people say, "Computers in process control? Yes—but you're talking about 20 years from now." If we are clever and apply the technical knowledge we now have, this period may be reduced by four to five years. This will probably involve radical changes in plant design, but the results are certain to be spectacular.

THE PIVOT ELEMENT FOR COMPUTER-PROCESS CONTROL

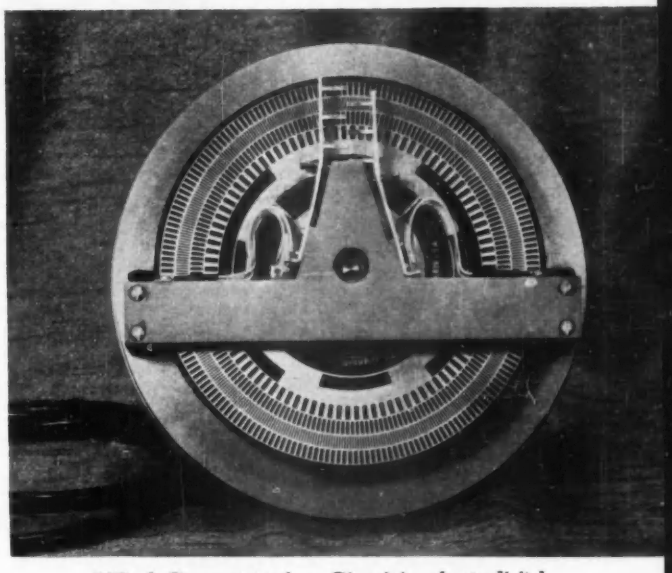
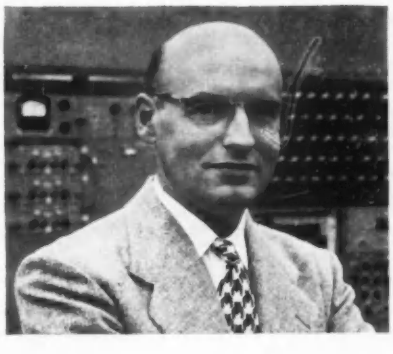


FIG. 3 Commutator from Giannini analog-to-digital converter. It gives 2,000 counts in 360 deg.



DR. EUGENE M. GRABBE

Dr. Eugene M. Grabbe, who led the project that resulted in the first airborne digital computer for automatic flight control, has been Senior Member of the Technical Staff of The Ramo-Wooldridge Corp. since 1954. In 1940, when he received his PhD from Yale, he was a research physicist at U. S. Rubber. In 1945 he went to Homelite Corp. as technical consultant on new product development, and in 1948 joined Hughes Aircraft Co. as associate head of the Computer Systems Dept. Dr. Grabbe is Los Angeles chairman of IRE's Professional Group on Automatic Control and Control Engineering's West Coast editorial consultant.

Factors in Selecting Valves for Compressible Flow

1—USUALLY, THESE FACTORS ARE IMPORTANT IN SELECTING A VALVE:

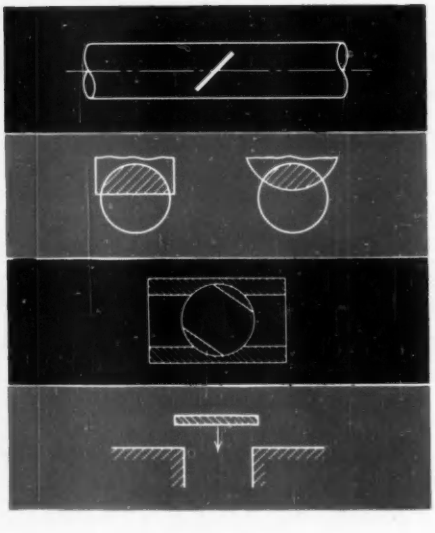
- VALVE SERVICE—ability to withstand extremes of temperature, pressure, vibration, corrosion, etc., and still maintain desired operation
- VALVE WEIGHT, which should be at a minimum
- VALVE MAINTENANCE costs; they are mainly functions of individual valve design and production methods.

2—BUT APPLICATION ENGINEERS SHOULD ALSO STRESS THESE POINTS:

- VALVE PERFORMANCE CHARACTERISTICS. Are they properly correlated with the system's operational characteristics? System components upstream and downstream of the valve must be considered.
- PURPOSE OF THE VALVE. Is it for shutoff, pressure regulation, flow regulation, temperature control, or something else?

3—PARTICULARLY IN CHOOSING ONE OF THE FOLLOWING VALVES:

1. BUTTERFLY VALVE (Fig. 1A)
2. SLIDE (OR GATE) VALVE (Fig. 1B)
3. BARREL VALVE (Fig. 1C)
4. POPPET VALVE (Fig. 1D)



GILBERT L. ROTH, Temco Aircraft Corp.*

A valve may be defined as a variable orifice—a device introducing a variable positive resistance into a fluid flow to permit flow regulation as required by a given system. Therefore, for a given valve position the valve characteristics are the same as for an orifice of some proportionate geometry.

The assumption that an ideal throttling valve should have linear variation in area with valve displacement is generally incorrect. So is the practice of minimizing pressure loss by using valves as large in diameter as the duct. Instead, valving should be considered in terms of (a) the overall pressure-loss coefficient, K, which is inversely proportional to flow velocity squared and does not, as a rule, vary directly with valve area, and (b), preventing sudden or excessive pressure and flow surges, which can cause overloads.

The pressure loss across a valve or orifice increases with the square of the fluid flow, as is shown in the following analysis. It should be noted that various entrance and discharge effects that vary with different valves or installations are included in the development of an overall pressure-loss coefficient to establish more fundamental and pronounced effects.

THE EFFECT OF RESISTANCE

Assuming a flow restriction (valve or orifice), the compressible adiabatic flow may be written:

$$Q_o = CA_1Y\sqrt{\frac{2g}{\rho_o}\,\frac{\Delta P_2}{\Delta P_2/\Delta P_v}} \qquad (1)$$

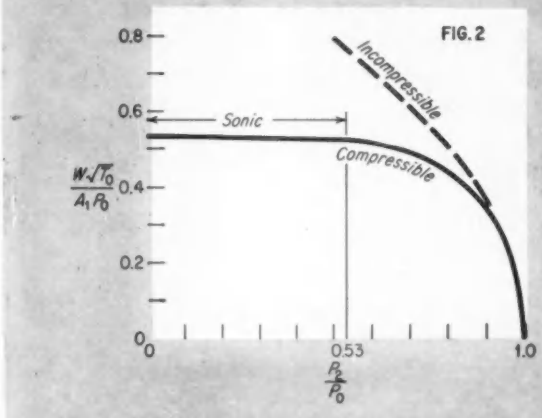
Since

$$Q_o = V_oA_o \qquad (2)$$

* Shortly after finishing this article, Mr. Roth left Temco Aircraft to join Convair at Fort Worth, Tex.

SIMPLE ORIFICE CHARACTERISTICS

FIG. 2



then

$$V_o = \frac{A_1}{A_o}\,CY\sqrt{\frac{2g\,\Delta P_2}{\rho_o}\times\frac{\Delta P_v}{\Delta P_2}} \qquad (3)$$

and

$$\Delta P_2 = \frac{V_o^2}{2g}\,\rho_o\left[\frac{(A_o/A_1)^2}{C^2Y^2}\times\frac{\Delta P_2}{\Delta P_v}\right] \qquad (4)$$

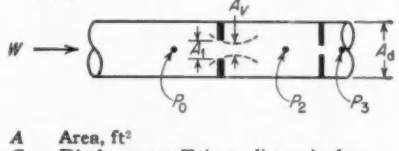
Since the pressure recovery ratio, $\Delta P_2/\Delta P_v$, and the discharge coefficient, C, depend primarily upon the area ratio, A_o/A_1; and the expansion factor, Y, depends upon P_2/P_o*, it is assumed that:

$$\frac{(A_o/A_1)^2}{C^2Y^2}\times\frac{\Delta P_2}{\Delta P_v} = \phi\left(\frac{A_o}{A_1}\right),\phi\left(\frac{P_2}{P_o}\right) \qquad (5)$$

*Y also depends on A_2/A_o, which is unity in a pipe of constant diameter.

THE SYMBOLS

FIG. 1



A	Area, ft²
C	Discharge coefficient, dimensionless (CA = effective area)
g	Acceleration of gravity, ft/sec²
K	Pressure loss coefficient, dimensionless
P	Pressure, lb/ft²
p	A dimensionless factor indicating relationship between valve resistance and overall system resistance; $p = \frac{\text{pressure drop across wide open valve}}{\text{pressure drop across valve + system}} = \frac{P_o - P_{2max}}{P_o - P_2}$
ΔP_2	Pressure differential, $P_o - P_2$, lb/ft²
ΔP_v	Pressure differential, $P_o - P_v$, lb/ft²
Q	Volume of flow, ft³/sec
T	Temperature, degrees Rankine
V	Fluid velocity, ft/sec
W	Fluid mass flow, lb/sec
Y	Compressibility factor, dimensionless
ρ	Density of fluid, lb/ft³
σ	Density ratio, actual density/standard density, dimensionless
ϕ	Function of . . .

SUBSCRIPTS

o	Valve inlet
1	Valve minimum area
2	Valve outlet (full recovered stream flow)
3	Downstream of fixed resistance or orifice
d	duct
s	standard conditions
v	vena contracta downstream of valve minimum area
max	valve open to its maximum free flow area
system	total for valve and fixed orifice(s)
valve	valve at any position

The area ratio, A_o/A_1, is dependent upon the valve position. Therefore, we can substitute a coefficient K for $\phi\left(\frac{A_2}{A_1}\right)$ such that K is dependent upon the valve position. Thus, using Equation 4 for compressible flow:

$$\Delta P_2 = K \frac{V_o^2}{2g} \rho_o \phi \left(\frac{P_2}{P_o}\right) \tag{6}$$

where K is a function of valve position. For incompressible flow, or any flow in which the pressure loss is low, $\phi\left(\frac{P_2}{P_o}\right)$ approaches unity. Making the proper substitutions in Equation 6:

$$\Delta P_2 = K \frac{V_o^2}{2g} \rho_o = K \frac{W^2}{2gA_o^2 \sigma \rho_s} \tag{7}$$

While for compressible flow, Equation 6 becomes:

$$K\phi\left(\frac{P_2}{P_o}\right) = \frac{2g\,\Delta P_2}{V_o^2 \rho_o} = \frac{2g\rho_o A_o^2\,\Delta P_2}{W^2} \tag{8}$$

Figure 2 is a plot of Equation 8 for compressible flow. The dotted line represents incompressible flow and has been drawn for purposes of comparison. The straight portion of the compressible curve indicates the range where the gas travels through the orifice at the speed of sound.

In the actual systems, where pipe friction must be considered, the duct also has a K, which depends on that length of duct which will cause the same pressure loss as an orifice of a given size.

The throttling characteristics of any valve may be specified in terms of the variation of K with valve motion. The flow resistance of a system can be expressed in terms of a K factor based on the fluid velocity at an arbitrarily chosen point. If this velocity is based on conditions at the valve inlet, the K's for the valve and the fluid system are directly additive, and the K of the complete system changes by the amount of valve K change when the valve is opened or closed. By this type of analysis a satisfactory calculation of the throttling effect of a valve can be made in any system.

Take, first, the simple case of a valve in a long, straight, smooth duct supplied by a source of constant pressure and discharging into a plenum (Figure 3A). If the duct's resistance is negligible (K for the valve is approximately equal to K for the system) and the valve alone controls the flow, the flow is directly proportional to the valve area, and the percentage of maximum flow is directly proportional to the percentage of maximum valve area (Figure 3B). In other words, the inherent flow-regulating characteristic (W/W_{max}) for a simple valve is linear.

If additional resistance to flow, such as a fixed orifice, is placed in the duct system (Figure 3C), the flow-regulating characteristic becomes non-linear. This can be proved analytically, but for these purposes, the final equation only will be stated. The equation for Figure 3D is:

$$\left(\frac{W}{W_{max}}\right)^2 = \frac{1}{1 + p\left[\left(\frac{A_{max}}{A}\right)^2 - 1\right]} \tag{9}$$

In any real system a length of duct is equivalent to a fixed orifice because of pipe friction. Therefore, Equation 9 holds in a real system consisting of only a duct and a valve.

An example of the effect of an orifice is in Figure 3D, an extreme case in which 90 per cent of the maximum valve area change will reduce the flow by only 30 per cent. This case is reasonably typical of airflow through throttling valves used as simple shut-off or flow-regulating valves.

THE EFFECT OF HOOK-UP

If two identical arrangements of the kind shown in Figure 3C are placed in parallel (Figure 4A) and the valves in both ducts are connected to make the valve area changes equal but in opposite directions (areas increase and decrease by the same amount), the flow characteristics in Figure 4B apply. The total flow characteristic, as shown, can be undesirable unless the fixed orifice is considerably larger than the maximum valve opening.

The arrangement in Figure 4A is termed a "by-pass" system. It is particularly important when physically different streams of gas (such as hot and cold air) are mixed. In addition to the flow characteristics, the flow ratio of one duct to the total flow must be considered in such a system. The flow ratios described for a hot-cold air regulating setup are termed the temperature-regulating characteristic of the system. This parameter is plotted against valve position in Figure 4C.

Another common bypass arrangement, a parallel system with one duct containing a fixed orifice and the other a valve, is shown in Figure 5A. Figure 5B gives the system's flow characteristics, and 5C the mixture temperature relationship.

Temperature- and flow-control equipment, which produce linear change in airflow with valve motion, give the greatest overall stability. In the case in Figure 4A, a small area ratio will cause increasing instability at the extremity of the scale.

Take a specific example. If, when the valve in Figure 5A is full open, the ratio of hot-air by-pass flow to cold-air flow is 8.0 (r=8.0), the maximum rate of uncontrolled temperature change is ten times that of the desired linear rate of change. In other words, near "close", where the rate of uncontrolled temperature change is at a maximum, the temperature control must be ten times as sensitive to maintain the same sensitivity as a control that gives a linear rate of change. With the valve 70% open, though, the rate of temperature change is below that of the linear valve and has, therefore, a greater stability. This system might be ideal for an engineer interested in that particular part of the scale.

THROTTLING EFFECT OF VALVES IN GAS SYSTEMS

VALVE CHARACTERISTICS

WITHOUT SYSTEM RESISTANCE ▶

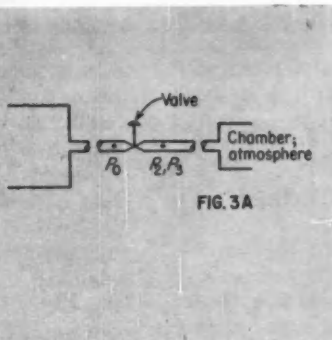


FIG. 3A

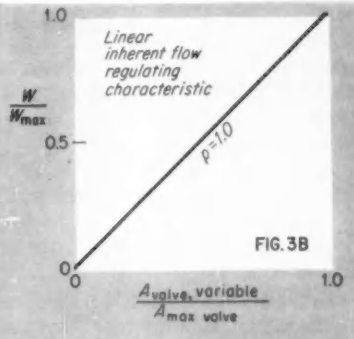


FIG. 3B

WITH SYSTEM RESISTANCE ▶

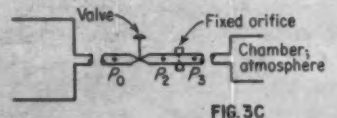


FIG. 3C

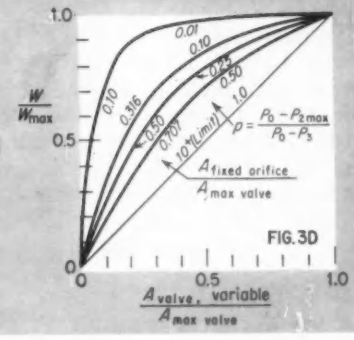


FIG. 3D

THE EFFECTS OF HOOK-UP:

"BY PASS" SYSTEM

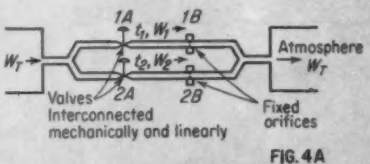


FIG. 4A

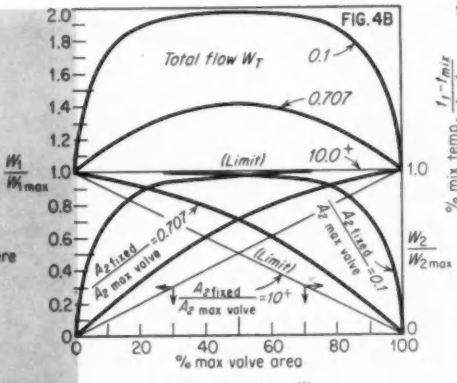


FIG. 4B

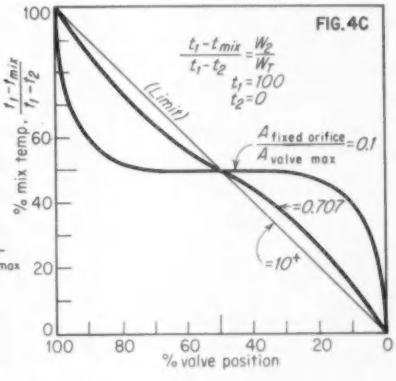


FIG. 4C

ANOTHER BY PASS HOOK-UP

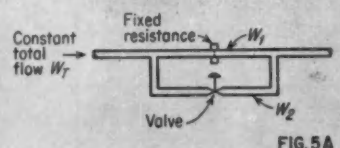


FIG. 5A

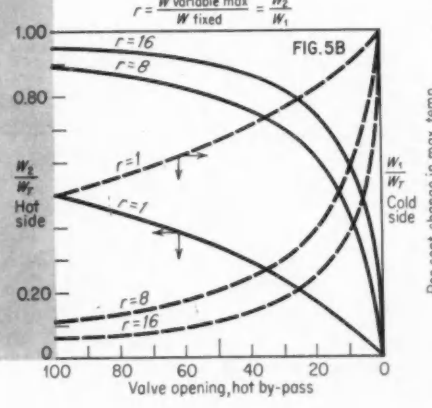


FIG. 5B

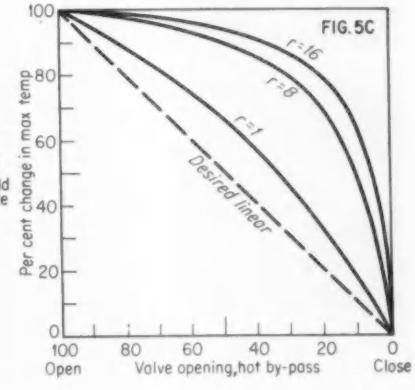


FIG. 5C

VALVES IN SERIES

In another common arrangement, two valves operate in series. A shut-off valve in series with a pressure-controlled flow valve is an example.

Assume a system in which one valve increases in area when another valve, in series with it, decreases in area and each valve:

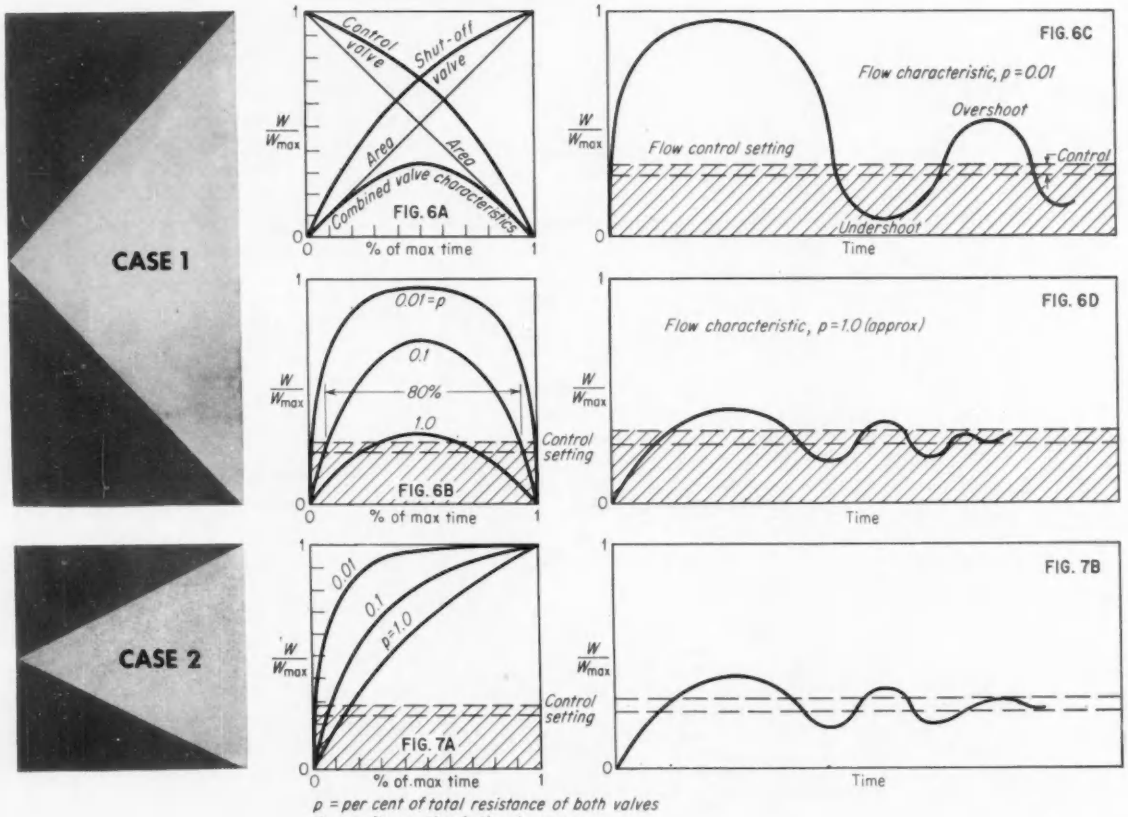
- is of the same size
- changes area linearly with time
- has the same timing full open to full closed
- is full open when the other is full closed

Figure 6A illustrates the inherent flow control characteristics of each valve and for the combination of valves in such a system. The actual flow control characteristics, as affected by system back pressure, are shown in Figure 6B.

If a flow control were designed to control such a system at a valve pressure loss of $p = 0.01$, with the flow set point at 30 per cent of full scale, a momentary surge of 330 per cent would occur. Control system stability is adversely affected by an initial surge of that nature. Figure 6C gives a qualitative picture of the expected flow control performance for a pressure loss ratio of $p = 0.01$. Figure 6D qualitatively portrays the improved control performance obtained with a less severe control characteristic—if $p = 1.0$.

If the system has two valves in series, both of which increase in area at the same rate, are full open and full closed together, and are otherwise similar to the valves of Figure 6, the effect of system resistance on control characteristics is shown in Figure 7A. The total characteristic is very similar to that of a single valve. If the set point of a flow controller is set at 30 per cent of full scale, the control performance shown qualitatively in Figure 7B would result. Note the small amount of excess flow and the quick return to the control point. A comparison of the cases in Figures 6 and 7 demonstrates the advantage of requiring the flow control valve to establish a full closed position upon closing of the shut-off valves (Figure 7).

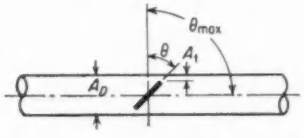
Some of the above analogies were simplified to avoid complexities caused by such variables as changes in the flow coefficients, electrical actuator time lag, pressure and temperature lag, etc. All of the examples chosen are based on the simple orifice analogy, which can be extended to any combination of valve-to-system relationships.



HOW FOUR VALVE TYPES PERFORM

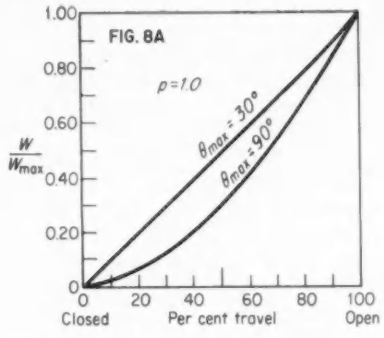
In actual practice valving does not conform to the true orifice situations used above to describe valve actions. The actual valve and its eccentricities are now considered.

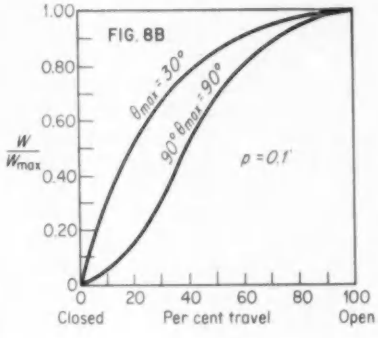
BUTTERFLY VALVES

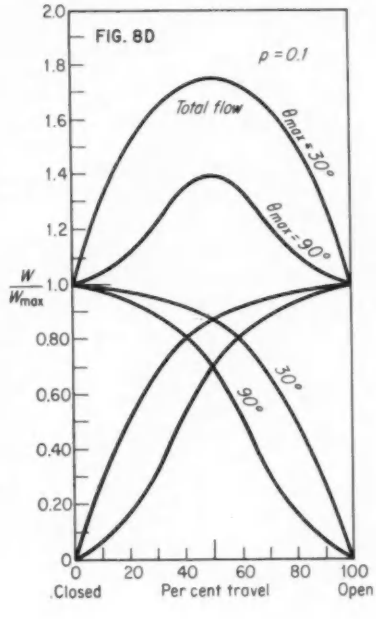


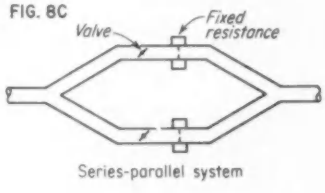
Typical flow-area characteristics of the butterfly valve are shown in Figure 8. 8A indicates the inherent flow characteristics, assuming unity for the combined coefficient of contraction and expansion, and 8B, the actual flow-control characteristics for 30 deg and 90 deg (maximum travel) valves with a pressure ratio of $p = 0.1$.

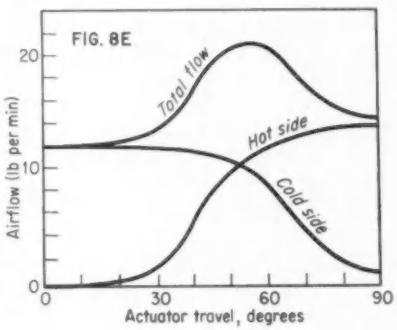
Figure 8D illustrates the control characteristic of two butterfly valves operated in a series-parallel arrangement (Figure 8C—see also Figure 4). 8E is an estimation of the flow with actual production valves in a series-parallel arrangement. Note the shift from left- to right-of-center.





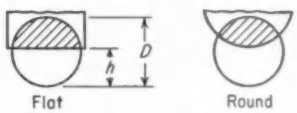


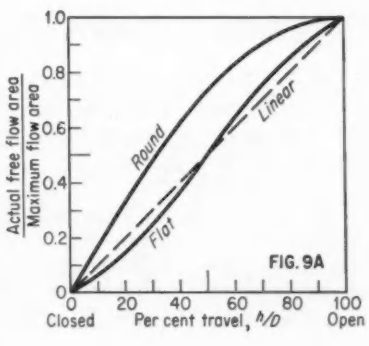


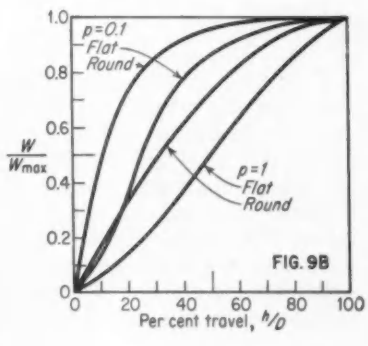


SLIDE VALVES

The slide valve has an inherent flow characteristic somewhat different from that of the butterfly. This is shown in Figure 9A. The valve's operational characteristic is shown in 9B. Curves are given for the two basic types of slide valves, flat face and round face. Of the two, the flat face has the better inherent flow characteristic compared with the linear (dotted line) characteristic.

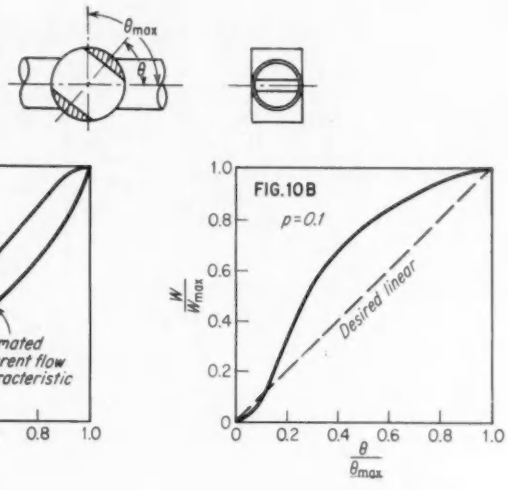






BARREL VALVES

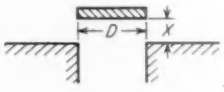
Figure 10A shows the area characteristic of the barrel valve, which operates through two pressure losses, contraction and expansion, in series. The calculated equivalent flow area, assumed to be the inherent flow characteristic, is also given in 10A. Described in 10B is the calculated actual flow characteristic of this valve for the same conditions as in the previous valve studies. Since it is difficult to predict flow through two non-centered orifices in series, Figure 10A is only an estimate.

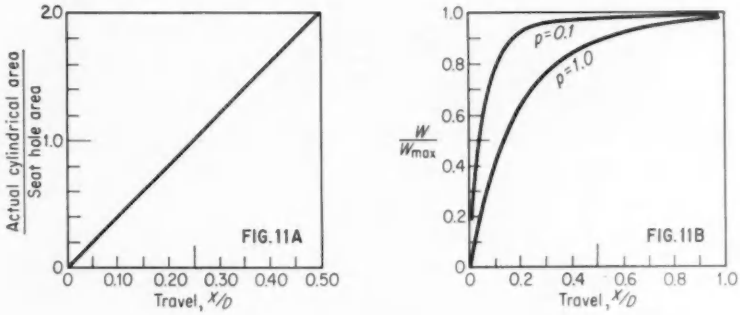


POPPET VALVES

The poppet valve also consists of two pressure losses in series, both of which have variable orifice characteristics. In the ideal situation, the flow area of the poppet is equal to the area of the hole when the distance from the hole is equal to one fourth of the hole diameter. Area characteristic (Figure 11A) is plotted as the ratio of the peripheral area to the area of the hole itself. The combined characteristic of the two pressure losses results in the inherent flow characteristic.

Results of tests on typical poppet valves were evaluated to check the calculated values shown. Values associated with the size of a particular poppet valve under consideration, and with its smoothed entrance effects deviated the most from the actual flow characteristics of the valve as given in Figure 11B.





THE TYPES COMPARED

For a final comparison, the results from all valves considered are plotted together in Figure 12A to show the differences in the inherent flow characteristics. The 30 deg butterfly, flat face slide, and barrel valves have the nearest to linear characteristics. 12B illustrates actual flow characteristics for all the valves. Note the similarity in control characteristics.

None of the valves, however, produces an acceptable characteristic in the sample situations discussed above. But these characteristics can be corrected by applying the proper amount of differential motion, as is shown in Figures 12C and 12D, through cam actuators, linkage actuators, etc.

Six Tips on Valve Selection

These analyses indicate that for a good flow-regulating characteristic, the designer must compromise wide-open-position pressure drop. In other words, valves must be considerably smaller than the duct system in which they are located. The principal

exception is a shut-off valve, whose operation cannot affect the other controls and parts. The following general conclusions are made:

► There is no broad rule that gives the ideal throttling characteristic for a valve, though it is obviously desirable to use a valve having a pressure-loss coefficient (K) higher over the larger part of its travel than that of the system in which it is to be used. Conversely, a low K in the full open position is desirable to keep pressure loss at a minimum when no throttling effect is wanted.

► When system resistance is the controlling factor, the type of valve used is of only minor importance in determining the flow- and temperature-regulating characteristics. Valve size and applied mechanical differential motion are more important. A possible exception is the high-recovery venturi-type valve.

► When the valve is the controlling resistance in a system, differences in the flow-regulating elements are important; here a valve with a near-linear inherent flow characteristic is probably the best.

► The common assumption that the ideal throttling valve should have linear area variation with displacement is generally incorrect. Rather, it should have linear variation in flow with displacement, which can be attacked in terms of K variation.

► Good flow-regulating characteristics represent uniform changes in flow or temperature, simultaneously allowing less potential flow, pressure, or temperature surge. They make it easier to provide stable flow, pressure, and temperature controls in a system.

► Extensive research is not necessary to provide a valve that will perform satisfactorily in a given system. Only major variables, such as system resistance and wide open valve resistance, need be considered.

Turn to page 124 for an excellent valve bibliography. Ed.

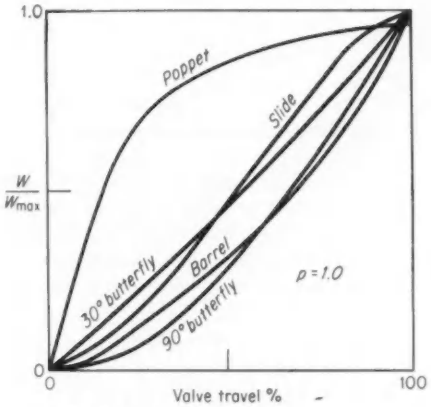


FIG. 12A - Inherent characteristics

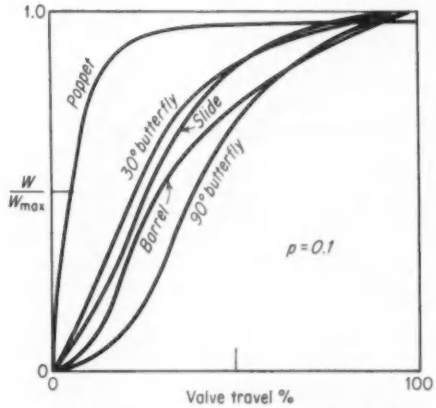


FIG. 12B - Actual characteristics with system resistance

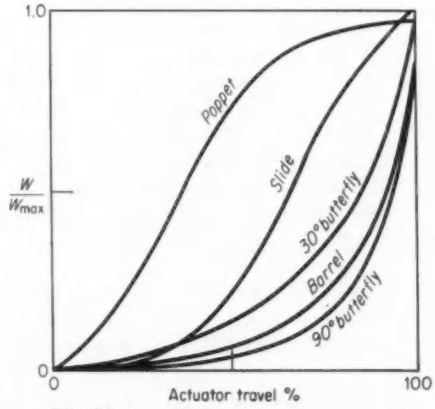


FIG. 12C - Inherent combined actuator and valve characteristics

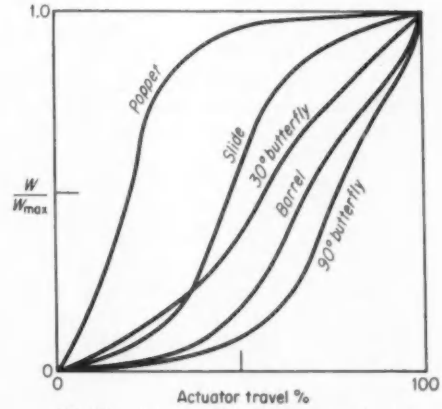


FIG. 12D - Actual combined actuator and valve characteristics with system resistance

NOTE: Poppet and slide valves are actuated by a three-bar linkage. Barrel and butterfly valves are actuated by a four-bar linkage.

A Practical Guide to Plant Controllability

PART II

J. M. L. JANSSEN, Royal Dutch/Shell Laboratory, Delft, Holland

REVIEW OF PART I: Plant controllability is a plant's potential for high-quality control. Several variables affect this potential (i.e., the disturbance; the control equipment; the plant itself). A useful tool for evaluating the effect of these variables is the deviation ratio: that factor by which automatic control reduces the effect of sinusoidal disturbances. In application, deviation ratio quantitatively compares deviations when the controller is inoperative against those caused by the same disturbances when the controller is operating properly. Because deviation ratio is defined in terms of sinusoidal disturbances, it describes the results of control in terms of frequency response.

Generally, deviation ratio values in the low frequency zone are small—indicating that feedback control has successfully reduced the effect of disturbances. Now, if the deviation ratio curves of two different plants—one with and one without dead time—are roughly plotted over the whole frequency range, their resonant peaks may coincide at about the same non-dimensional frequency and the deviation ratio curves seem to differ very little. However, justification for the common belief that dead time impairs control is confirmed when the deviation ratio curve is closely scrutinized in the low frequency zone alone.

Part I of author Janssen's discussion offered four fundamental rules for improving a plant's potential for high quality control. In this concluding section the author elaborates on such important points as control of low frequency disturbances, the "as-if" disturbance, deviation reduction of non-sinusoidal disturbances, and actual simulated and in-plant test results, and develops four more practical rules:

1. The greatest reduction in deviation resulting from a disturbance to the process is obtained by minimizing the product of the proportional band and the reset time. This minimum often occurs at a proportional band about five times the ultimate proportional band.

2. "Inverse derivative" action can be used to reduce, at low frequencies, the magnitude of the deviation resulting from a disturbance.

3. A step disturbance results in a peak deviation equal to about 1.5 the step amplitude divided by the attenuation for a pure sine wave of resonance frequency between the point of incidence of the disturbance and the point where the deviation is measured.

4. A ramp disturbance results in a peak deviation value equal to about one-half the rise of the disturbance, during one period of oscillation at the resonance frequency, divided by the attenuation between the point of incidence and the point at which the deviation is measured. Here, again, the attenuation equals that obtained for a pure sine wave of a frequency equal to the resonance frequency.

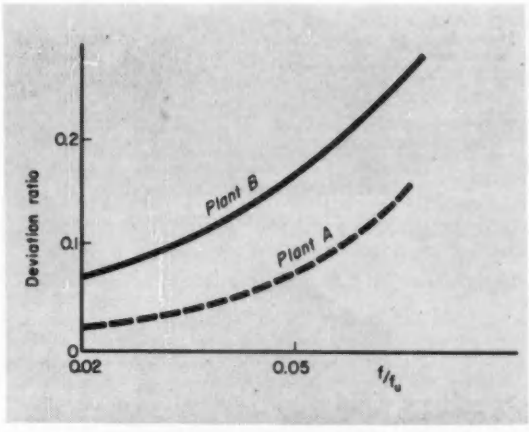


FIG. 1. The deviation ratio curve expanded in the low-frequency range. Plant A has little time lag, while that of Plant B is somewhat greater. The lower values of the deviation ratio for Plant A show that feedback control aids in the reduction of deviations when the plant has little dead time.

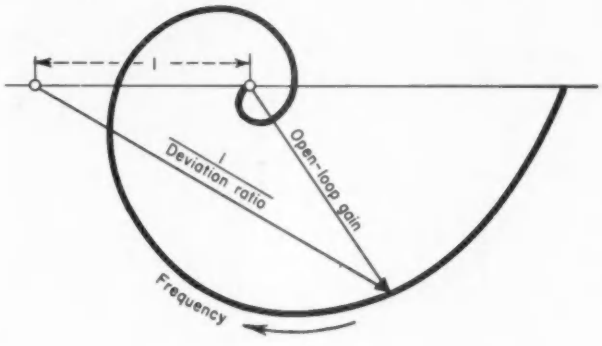


FIG. 2. At low frequencies the deviation ratio is inversely proportional to the open-loop gain, as shown in the above frequency response plot of the open-loop transfer function of a typical process and controller system. Thus, for best reduction of deviations, a high gain at low frequencies is desirable.

The low frequency zone of the deviation ratios for two different plants is shown in Figure 1. The transfer function of Plant A has one exponential time lag of unity time constant cascaded with two lags of time constant 1/30, while the transfer function of Plant B has an exponential lag of unity time constant cascaded 11 times. This large number of cascaded time constants in Plant B introduces *dead time* in the plant. The fact that this *dead time* impairs control is verified in Figure 1 by the greater values of deviation ratio for Plant B than for Plant A. Smaller deviation ratio values mean better reduction of disturbance by the controller.

The frequency response curve of an open-loop system, Figure 2, indicates that the deviation ratio, at low frequencies, is inversely proportional to the open-loop gain. Thus, if low-frequency control is the important thing, then the open-loop gain should be made high. However, the low-frequency gains that can be attained from the two processes, Plants A and B, clearly show, K in Figure 3, that much higher gains obtain from plants without *dead time*. Here, in either case, the gain is inversely proportional to the frequency and directly proportional to K:

$$\text{low-frequency gain} = \frac{1}{2\pi} \cdot K \frac{f_u}{f}.$$

Figure 3 shows the factor K in terms of the proportional gain of the controller and the resonance frequency, for a peak d.r. value of two (Figure 1, Part II, and Figure 3, Part I). Maximum gain occurs when the product of proportional band and reset time is a minimum. This condition can be met with a rather wide proportional-band setting (often about five times the ultimate proportional band) and a short reset time.

Increased low-frequency gain through the use of the so-called "inverse-derivative" action deserves attention. The response to a step change for an "inverse-derivative" unit appears to have *proportional plus non-ideal integral action* (Figure 4A). This figure indicates a low-frequency gain of about six. The application of this particular "inverse-derivative" unit to Plant B reduces deviation significantly, as the lower value of deviation ratio in Figure 4B indicates. The full improvement by a factor of six would obtain for frequencies lower than those shown in the diagram.

THE AS-IF DISTURBANCE

In feedback control, the disturbance itself cannot be influenced. Take, for example, the temperature control system of Figure 5. Here the temperature affects fuel supply only, but not the system throughput. Thus, a variation in throughput, with or without control, presents a very real disturbance, but it remains unaffected by control. By dividing both the numerator and the denominator of the deviation ratio by F_i, the direct transfer path (see Figure 1, Part I), the deviations with and without control are referred back to their causes, namely, the disturbances.

This amounts to adopting the attitude of an observer who does not know that the plant is under control. When he notices a reduction of the deviation by, say, a factor of three, he explains this as caused by a reduction of the disturbance by the same

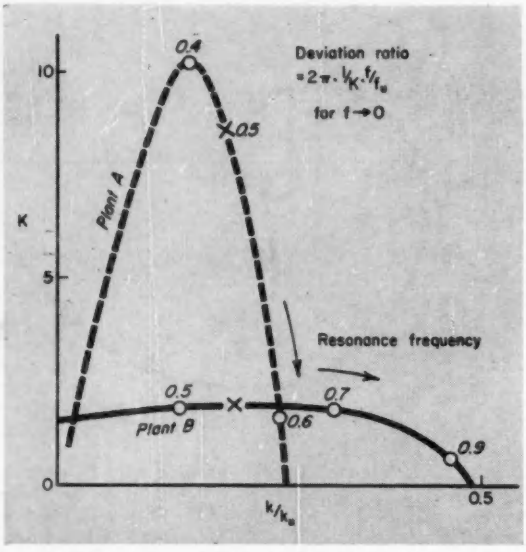
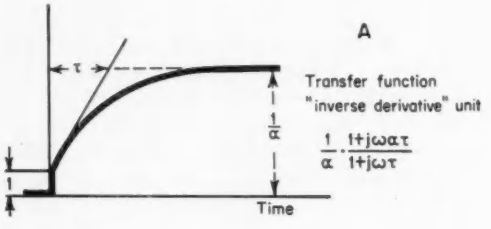


FIG. 3. For best reduction in deviations (small value of deviation ratio) at low frequencies, the factor K should be high. Here, K is evaluated in terms of the proportional gain of the controller. The higher values of K for Plant A indicate the significance of these curves: plants with little dead time exhibit lower deviation values because of increased attainable gain at low frequencies.



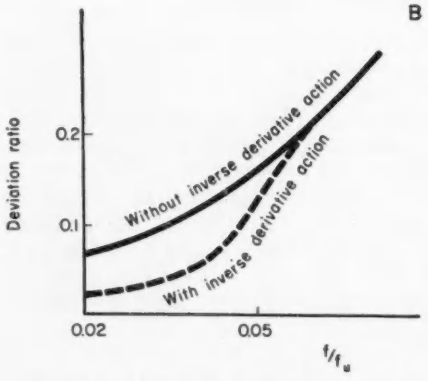


FIG. 4. "Inverse-derivative" action, as in the transfer function above, contributes to increased gain at low frequencies. Therefore, the deviation ratio reduces to a lower value, as in 4B.

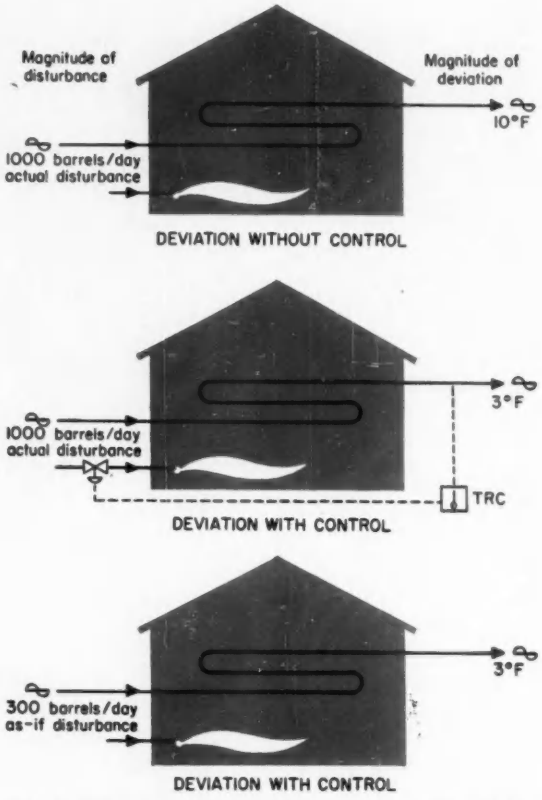


FIG. 5. When a system has a throughput of 1,000 bbls/day without control, the resulting deviation is 10 deg. F. However, the addition of a temperature controller reduces the deviation to 3 deg F. The disturbance (or throughput) then appears "as-if" it were only about 300 bbls/day, giving the same deviation of 3 deg. F.

factor. This reduced disturbance is the "as-if" disturbance. But actually the disturbance has not changed at all.

NON-SINUSOIDAL DISTURBANCES

The concept of the "as-if" disturbance, while only a mental tool, plays an important part in the analysis of deviation reduction of non-sinusoidal disturbances. When deviations or disturbances are of a non-sinusoidal form, the *deviation ratio* can still be applied—if the frequency components of the non-sinusoidal forms are each treated separately.

For instance, if a *step disturbance* enters the plant, control reduces the effect of each frequency component separately through the *deviation ratio*. Similarly, each frequency component of a *step deviation* is reduced by the deviation ratio. Consequently, control affects a *step disturbance* and a *step deviation* in exactly the same way.

Thus the "as-if" disturbance in the first case has the same form as the deviation with control in the second case: this form is the familiar oscillatory response seen on the chart of a recorder-controller after a sudden set-point change.

This oscillatory response can be used as a starting point for finding a simple relationship for predicting (if only approximately) at least the peak height of the deviation resulting from either a *step* or a *ramp disturbance*. The graphical representations of these disturbances and their resulting deviations analyze these relationships in the following sections.

Step Disturbance

The "as-if" disturbance transfers to the controlled variable as if there were no control. Figure 6A shows a *step-disturbance*, the "as-if" disturbance, and the resulting deviation. On the path from its point of incidence to the controlled variable the "as-if" disturbance undergoes an attenuation. This attenuation must be roughly equal to the attenuation along this path for a pure sine wave of a frequency that practically equals the resonance frequency. This same idea, stated another way, results in the following rule:

- The ratio between the magnitude of a step disturbance and the peak value of the resulting deviation is "roughly equal" to the attenuation of a sine wave of resonance frequency between the point of incidence of the disturbance and the controlled variable.

"Roughly equal" can be specified more exactly. For *step disturbances* to the manipulated variable and for rather tight controller settings "roughly equal" means "about 1.5 times less". However, Figure 7 shows a more exact factor (β) for Plants A and B as determined by the proportional band and the reset rate.[1, 2]

In the above examples the disturbance works at the plant input. If the disturbance affects the controlled variable along a path with less time lag, then the β factor will be less than 1.5; in the extreme case of no time lag, β equals unity. On the other hand, if the disturbance affects the controlled variable along a path with much longer time lags than those of the plant, the value β becomes rather uncertain.

Ramp Disturbances

The analysis of a *ramp disturbance* stems directly from the *step disturbance*. A *ramp* (constant rate) change is simply the integral of the *step* change; therefore, the integral of the effect of the *step disturbance* equals the effect of a *ramp disturbance*. Figure 6B shows the *ramp disturbance* obtained from Figure 6A, and the resulting integrated effects.

In control systems incorporating one integration,

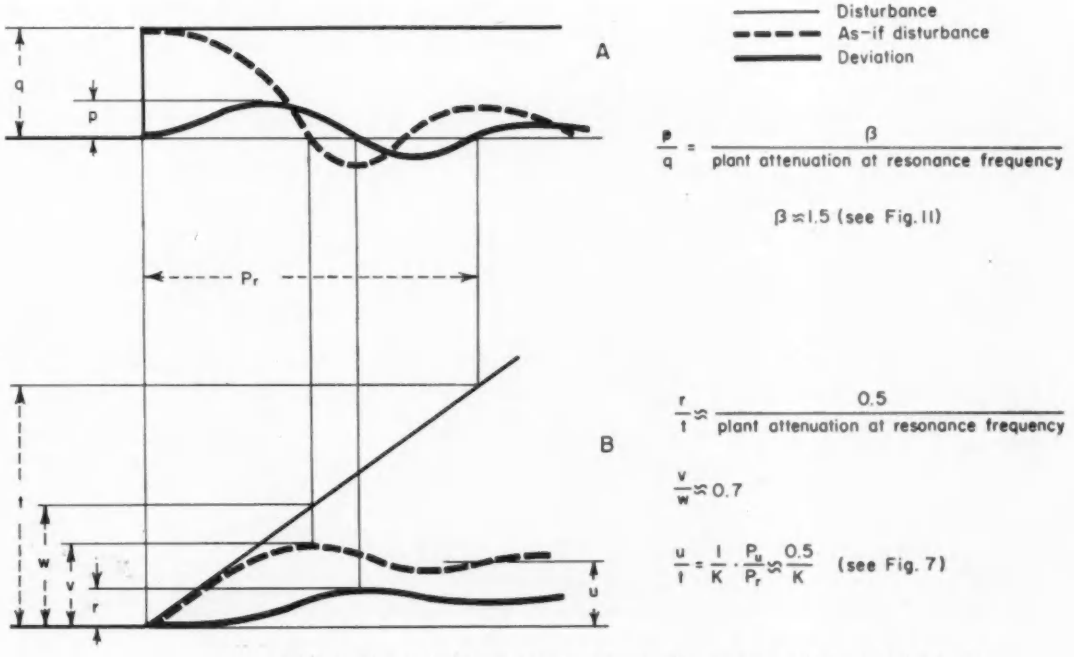


FIG. 6. Curves in Figure 6A show a step disturbance applied to a plant, the "as-if" disturbance, and the resulting deviation. The effects of a ramp disturbance (Figure 6B) derive from the integration of the effects of the step disturbance.

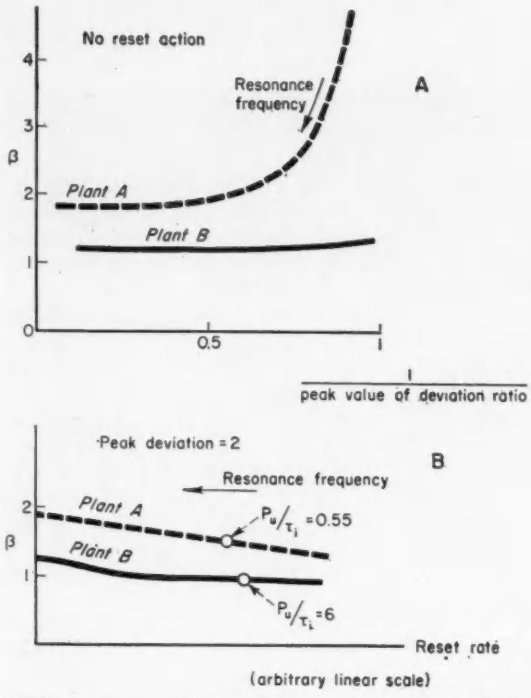


FIG. 7. More exact values for β in Figure 6A result from Figure 7A. Here β depends not only on the dead time of the process, but also on the peak value of the deviation ratio. The proportional gain of the controller, in turn, very strongly influences this peak value. In Figure 7A there is no reset action, but 7B shows the effect of reset rate on the β factor when the peak value of the deviation ratio remains constant at the conditions used in the overall discussion—namely, a value of two.

the "as-if" disturbance settles down, after a few oscillations, to a constant value, u. This value is proportional to the rate of change of the disturbance, t/P_r. The factor K in Figure 6B is the same parameter that determines the low-frequency part of the *deviation ratio* (see Figure 3).

Perhaps the peak value, v, of the "as-if" disturbance, resulting from a *ramp disturbance*, gives more information. In practice, the *ramp disturbance* will not continue to rise, so that the "as-if" disturbance goes back to zero (because of reduced slope of disturbance) instead of remaining at a constant value. The peak height, which can be expressed graphically, as in Figure 6B, also characterizes the resulting deviation, as shown in this figure. However, this value is rather uncertain, and the coefficient 0.5 should be taken with a grain of salt.

COMPUTER AND IN-PLANT RESULTS

An electronic process-control simulator, developed in the Royal Dutch/Shell Laboratory, facilitates investigating the effect of controller-setting. This analog computer easily overcomes the slow response usual in many industrial processes by simulating equivalent responses on a reduced time scale. Thus, a vast amount of experience can be accumulated in a short time. The simulator contains several fixed processes as well as a *delay line synthesizer* to introduce adjust-

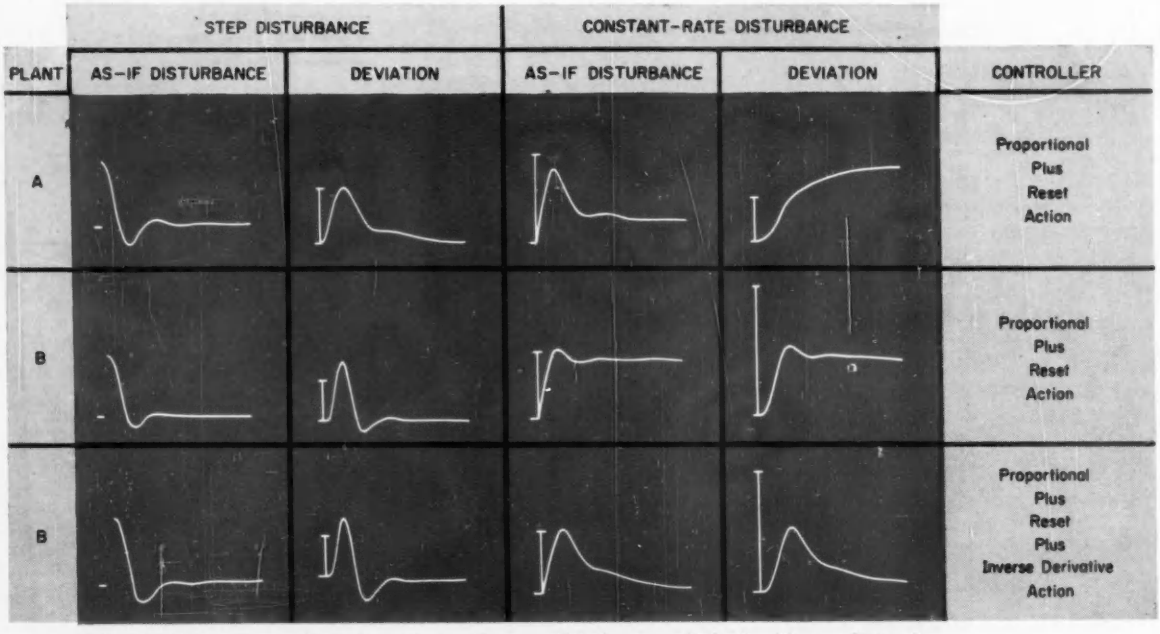


FIG. 8. Deviations resulting from step and ramp disturbances, obtained with an electronic process-control simulator, show some of the possible effects for plants. In these tests both the plants and the controller actions were simulated on the computer to expedite information gathering. Vertical marks indicate calculated peak heights per calculations in Figure 6.

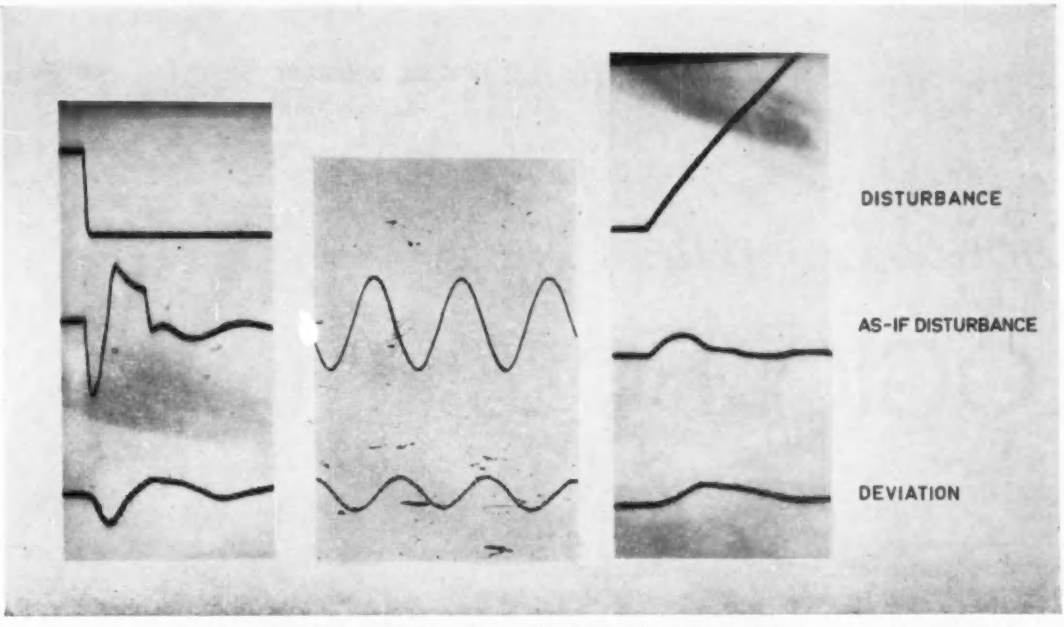


FIG. 9. These photographs show the results of actual in-plant tests taken on the pressure control system of a pilot-plant distilling column. Step, sinusoidal, and ramp disturbances upset the heat input. The "as-if" disturbance came from actual change in the valve pressure and the deviations show how the controller corrected the effects of the disturbance. Time scale: one period of the sine wave (middle group) equals about 28 sec.

able plant responses. Additional circuits also simulate the various controller actions.

Figure 8 reveals typical computer responses to disturbances applied to two simulated processes, one with little dead time (Plant A) and one with much more dead time (Plant B). Of particular interest are the effects of "inverse derivative" action on the resulting deviations and disturbances.

Results of actual in-plant tests are shown in the photographs in Figure 9. Here the responses result from disturbances applied (by means of an adding relay) to the heat input of the pressure control system of a pilot-plant distilling column. The actual change in valve pressure represents the "as-if" disturbance. The fact that the period of the sinusoidal "as-if" disturbance equals 28 sec gives some idea of the time scale involved in these measurements.

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1. *THE PRACTICAL APPLICATION OF FREQUENCY RESPONSE ANALYSIS TO AUTOMATIC CONTROL*, C. I. Rutherford, Proc. of Inst. of Mech. Engrs., Vol. 162, pp. 334-354, 1950.

2. *THE FREQUENCY RESPONSE APPROACH TO AUTOMATIC CONTROL PROBLEMS*, A. R. Aikman, Trans. Soc. Inst. Tech., Vol. 3, pp. 2-16, 1951.

STILL MORE ON PROCESS CONTROL ANALYSIS

Mr. Janssen's article and others in the past (i.e., Paynter, Reswick, Reynolds) on plant-process control have brought enthusiastic calls for "more of the same". In response the editors are planning two new series:

► Starting in the next issue will be the first of a group of articles by Taylor Instrument Cos. authors on the techniques of process control analysis. To be covered: computing process dynamics; controlling modes; cascade control.

► A four-part discussion by John Dobson on the control of fractionating columns will start early in 1956. This will be one of the first published studies of the control dynamics of a unit chemical process.

Digital Computers Need
LOGICAL DESIGN

ELDRED NELSON, The Ramo-Wooldridge Corp.

THE GIST: Programmed automatic operation constitutes one of the most important features of digital computers. In such computers discrete electrical signals control the sequence of arithmetic and logical operations. These control signals, recorded in digital memory devices, cause the computer to automatically perform one computational step after another. Changing the recorded control signals changes the problem.

Thus, only the finite capacity of the memory devices and the time available limit the computation that can be programmed in terms of the elementary operations of the computer. If its elementary operations include addition, subtraction, multiplication, and division, plus a few logical and memory transfer operations, it performs practically any computation and is known as the "general purpose computer".

In digital computers for general purpose tasks, the signals, circuits, and memories involved have these six basic properties:

1. Discrete electric signals represent numbers, alphabetical characters, punctuation marks, etc.
2. Switching circuits perform arithmetic operations on these signals, and such logical operations as comparing two numbers.
3. Other signals, similar to those representing numbers, control the switching circuits.
4. These control signals can be interpreted numerically, in the same manner as those signals that represent numbers.
5. Digital memory devices store discrete electrical signals; these signals can then be read back at a later time.
6. The digital information stored in the memory devices develops, in turn, discrete control signals. It is this principle that permits automatic operation of digital computers.

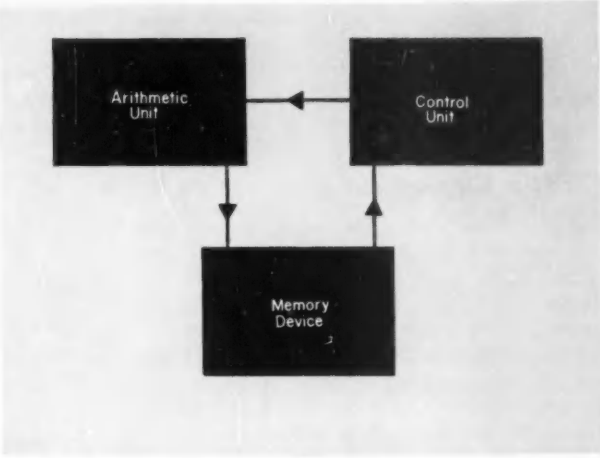

FIG. 1. Block diagram of digital computer reveals basic operations within the computer. The arithmetic unit performs arithmetic and logical operations. The control unit generates discrete electrical signals that specify the order of operations for the arithmetic unit. And the digital memory device stores numbers and control instructions.

In automatic programmed computers, a digital memory device sends control instructions to the control unit, which interprets these instructions and generates other signals that control the operation of the arithmetic unit. Figure 1 shows the functional block diagram of a computer in terms of these three units:

- The arithmetic unit, which through its switching circuits, performs arithmetic and logical operations in any order
- The control unit, which generates discrete electrical signals that specify the order of operations for the arithmetic unit
- The digital memory device, which stores numbers and control instructions

DIGITAL COMPUTER SIGNALS

The discrete nature of the signals appears in the discrete changes in voltage level that take place at discrete intervals of time. A timing or "clock" signal defines the intervals within which a digital interpretation is put on the waveform characteristics of the computer signals.

Most digital computers use signals having two waveform states. Hence, the digital interpretation of these signals involves the assignment of the binary digits *0* and *1* to these states. Actually, a sequence of binary digits represents the logical properties of digital computers. A typical sequence of digits is shown in Figure 2.

Rules are required for the interpretation of signal digits. For instance, in Figure 2, the sequence of signals may be interpreted in the straight binary system or in a coded binary system. In the first case, each signal digit stands for a digit of a binary number and thus the number combination becomes *01100101*. However, in the case of a binary-coded decimal, each binary group of four signal digits represents a decimal digit. Therefore, under the rules of binary-coded decimal numbers, this same sequence of signals results in the decimal value 65—of these signals involves the assignment of the

The use of symbols, such as *A*, *B*, *v*, etc., to denote these signals is the basis of mathematical expressions for the logical properties of digital computers. Each such symbol denotes a signal and is called a "signal variable". The signal variable takes on the value *1* when the signal it represents has the value *1*; and it takes on the value *0* when the signal has the value *0*. This signal variable contains all of the logical properties of the signal that it represents.

Here, the time variation of the signal can be included in the representation of the signal variable. For instance, changes in the signals occur at times

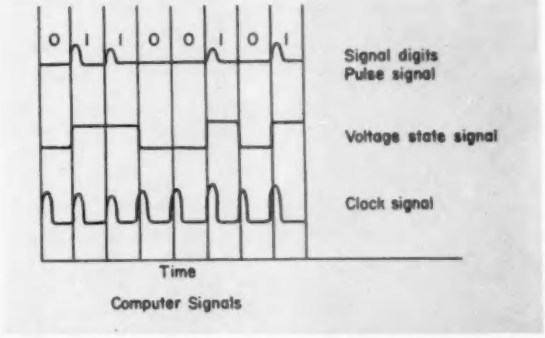

FIG. 2. Binary numbers used in digital computers are represented by two-state voltage pulse signals. Under the influence of a clock signal the pulse digits convert to high or low voltages equivalent to binary 1 or 0. Thus, a binary number is represented by a sequence of voltages in time.

t_1, t_2, t_3 . . . ., where these times are discrete intervals as defined by the clock signals. Thus, A_1 denotes the value of the signal variable A in the time interval following t_1, A_2 in the time interval following t_2, and, in general, A_n in the time interval following t_n.

SWITCHING CIRCUITS

A class of circuits, called *switching circuits*, performs the actual computations in a digital computer. They operate on the discrete electrical signals representing numbers to produce new discrete signals that may be interpreted as the numerical result of the arithmetic operation. Some of the switching circuits are the *inverting amplifier*, the *and* gate, the *or* gate, the *flip-flop*, the *binary adder*, and a circuit for the comparison of two numbers.

Inverting Amplifier Gives Complement Function

One of the simplest switching circuits is the *inverting amplifier*, shown in Figure 3. The heart of this circuit is a triode vacuum tube. The cathode is grounded, while a resistance R connects the plate to a positive potential, V_1. The signal A is applied to the grid and a signal F results at the plate. Signal A has two states—a potential near ground and a negative potential beyond the tube cutoff potential. Here, the higher potential (ground) is assigned the logical digit value *1*, and the lower value (cutoff) is assigned the value *0*.

As a result of the above circuit connection and arbitrary assignment of the input values, the output F must also have two signal states. But these values now are the inverse of the input signal at the grid: when the tube is cut off (A equals *0*) F equals *1*, and when the tube is conducting (A equals *1*) F equals *0*.

Mathematically, a *function* of A relates F to A. If the circuits required are for the moment neglected, one sees there are only four ways in which the function values *0* and *1* can be assigned to the values *0* and *1* of the single variable, A (Table 1):

TABLE 1

A	F^1	F^2	F^3	F^4
0	0	0	1	1
1	0	1	0	1

These functions are very simple. Function F^3 obtained from the circuit of the inverting amplifier carries the name *complement* and the symbol $\bar{A}$ because of its extreme importance to logical design.

The *And* Gate Circuit

Two simple *switching circuits* illustrate the properties of functions of two variables, A and B. The first of these, the diode *and* gate, is shown in Figure 4. Here, the anodes of two diodes are connected, first together and then through a resistor R to a positive potential V_1. Input signals A and B are applied to the cathodes of the diodes. The digit values *0* and *1* correspond to the potential values E_0 and E_1, where E_1 is the higher value. Then V_1 is chosen to be higher than E_1. Thus the output signal C equals a potential near to the lower of the potentials of signals A and B. Table 2 relates signal variable C to input variables A and B.

TABLE 2

A	B	C
0	0	0
0	1	0
1	0	0
1	1	1

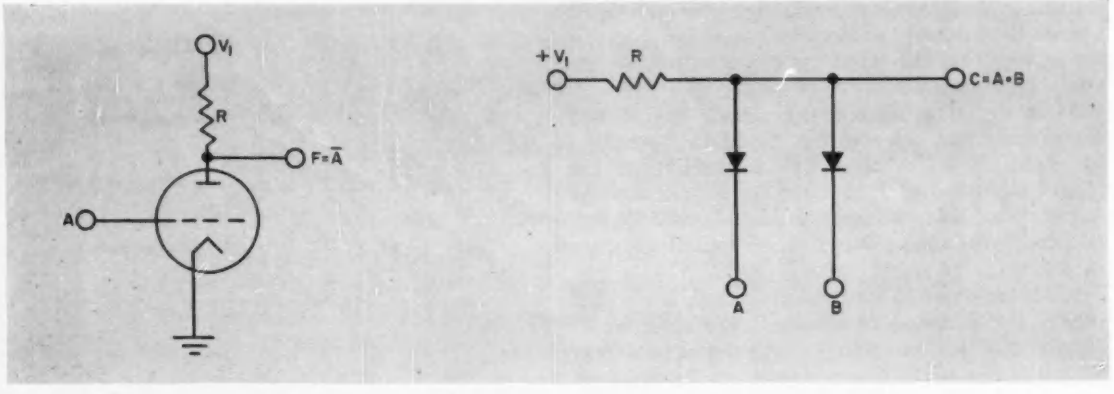

FIG. 3. The inverting amplifier develops, at the output, the complement of the input signal. Therefore, if the voltage at A is high, then the voltage at F is low.

FIG. 4. The AND gate circuit develops the product of the two binary input signals, A and B, or C equals A•B.

Note from this table that output C may be written as the product of the signal variables A and B, or C equals A·B. This algebraic notation retains the properties of multiplication, and results from the common anode connection of the diodes.

The Or Gate Circuit

Figure 5 shows another simple *switching circuit*, the or gate. In this case the cathodes of the diodes are connected, first together and then through a resistor R to a potential V_0. Signals A and B are applied to the anodes of the diodes, and digit values *0* and *1* correspond to potentials E_0 and E_1. V_0 is less than E_0, so that the output signal C has a potential near to the higher of the potentials of signals A and B. Table 3 relates the signal variable C to the input signals A and B.

TABLE 3

A	B	C
0	0	0
0	1	1
1	0	1
1	1	1

This function of A and B is denoted by $A + B$, or C equals A plus B.

The *Flip-Flop* Circuit

The *flip-flop* switching circuit has this characteristic: its output signal depends on its input signal during the preceding time interval. This feature also gives it the attribute of *memory*. The *flip-flop* has two inputs which may be denoted by J_n and K_n, and two complementary outputs—Q_n and $\overline{Q}_n$. Table 4 shows the functional relationship of these signal variables.

TABLE 4

J_{n-1}	K_{n-1}	Q_n
0	0	Q_{n-1}
0	1	0
1	0	1
1	1	$\overline{Q}_{n-1}$

The algebraic form of the tabular arrangement is:

$$Q_n = \overline{J}_{n-1}\overline{K}_{n-1}Q_{n-1} + J_{n-1}\overline{K}_{n-1} + J_{n-1}K_{n-1}\overline{Q}_{n-1}$$
$$= \overline{K}_{n-1}Q_{n-1} + J_{n-1}\overline{Q}_{n-1}$$

Here the simpler form of the equation was obtained through Boolean algebra, which is used extensively in logical design. Note that the equation is a difference equation in the time variable n, and expresses Q_n in terms of values of signal variables in the preceding time interval. This is characteristic of computer elements that can carry over a signal from one time interval to the next.

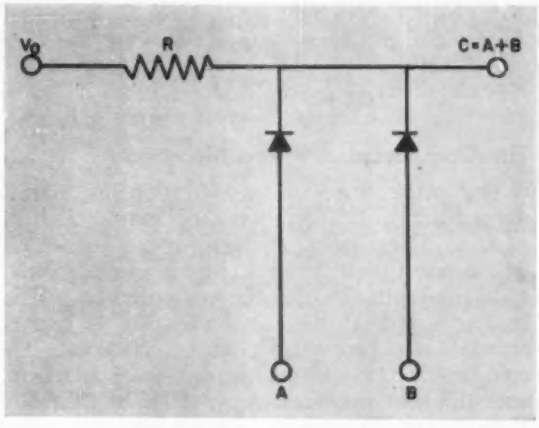

FIG. 5. The OR gate circuit develops the sum of the two binary input signals, A and B.

The Binary Adder

The operation of the *binary adder* illustrates how computer algebra can be used to design the logical properties of switching circuits composed of *flip-flops* and gates. Let A_n and B_n be signal variables representing the numbers to be added. Then the rules for binary addition are shown in Table 5.

TABLE 5

A_n	B_n	S_n	C_n
0	0	0	0
0	1	1	0
1	0	1	0
1	1	0	1

Here, S_n is the signal variable representing the *sum* digit, and C_n the signal variable representing the *carry* digit that arises when the binary sum exceeds *1*. The algebraic form for Table 5 becomes

$$S_n = \overline{A}_n \cdot B_n + A_n \cdot \overline{B}_n$$

and

$$C_n = A_n \cdot B_n$$

Figure 6 shows the diode network that realizes the adding operations of the above equations. If A_n and B_n come from flip-flops Q_n^1 and Q_n^2, then the two signal variables A_n and B_n, and their complements $\overline{A}_n$ and $\overline{B}_n$, are available at the input terminals.

However, the binary adder developed so far is not complete, for it does not take into account the handling of the *carry* digit C_n. This carry digit must be stored until the next digit time, assuming the computer operates serially on the signals. Another *flip-flop*, Q_n^3, accomplishes the storage of the carry digit; here C_n connects to the inputs of this *flip-flop*. Then the inputs relate to the original digits to be added as follows:

$$J_n^3 = C_n = A_n \cdot B_n$$
$$K_n^3 = C_n = \overline{A}_n + \overline{B}_n$$

Also the previous carry C_{n-1} must be added to S_n, where C_{n-1} is determined from the following:

$$Q_n^3 = \overline{K}_{n-1}{}^3 Q_{n-1} + J_{n-1}{}^3 \overline{Q}_{n-1} = C_{n-1} Q_{n-1} + C_{n-1} \overline{Q}_{n-1} = C_{n-1}$$

Then the correct binary sum and carry are:

$$S_n^1 = \overline{S}_n^1 \cdot Q_n^3 + S_n^1 \cdot \overline{Q}_n^3$$
$$C_n^1 = \overline{S}_n^1 \cdot Q_n^3$$

The Comparison of Two Numbers

The performance of switching circuits extends beyond arithmetic operations on discrete electrical signals. These extra operations are called *logical*. The comparison of two numbers is an example.

To illustrate this, let the computer be a serial computer and let the signal variables A_n and B_n represent the two numbers to be compared. The comparison proceeds serially, digit by digit, starting with the least significant digit. Thus, at each digit time, the circuit compares the corresponding digits of the two numbers.

The signal variable C_n equals $A_n \cdot \overline{B}_n$ will have the value *1* if the current digit of *A* is larger than the current digit of *B*; it will have the value *0* if the two digits are equal or if the digit of *B* is greater. During the first time interval the signal furnishes the results of the comparison for one digit number. During the second digit time there is needed, in addition to C_n, the result of the comparison during the preceding interval.

Once again the memory feature of the *flip-flop* serves to advantage. Here, input signals to Q_n are

$$J_n = C_n = A_n \cdot \overline{B}_n$$
$$K_n = \overline{A}_n \cdot B_n$$

Then the *flip-flop* signal Q_n indicates the result of the comparison as of the preceding digit time. Note that if the digits A_n and B_n are equal, the state of the flip-flop is not changed.

CONTROL OF SWITCHING CIRCUITS

The start and stop of arithmetic and logical operations can be effected by other discrete electrical signals. These signals control the operation of switching circuits. For instance, the stopping of a computer operation is accomplished by forcing a key signal of this operation to take on a specified value. Thus, signal variables, say F_n and K_n, represent the signal to be controlled and the control signal.

Then, in the new signal variable,

$$G_n = F_n \cdot K_n$$

formed from F_n and K_n, G_n has the value *0* whenever the control signal K_n has the value *0*, and it has the value F_n whenever K_n has the value *1*. Incidentally, this procedure applies to the comparison device previously discussed.

Altering the input signals J_n and K_n with a control signal, say R_n, accomplishes the control of the comparison circuit.

$$J_n = R_n \cdot A_n \cdot \overline{B}_n$$
$$K_n = R_n \cdot \overline{A}_n \cdot B_n$$

Then the comparison *flip-flop* receives input signals that can change the state of the circuit only during the time that the control signal has the value *1*. When R_n becomes *0*, the comparison ceases and the *flip-flop* Q_n indicates the result of the comparison.

In general, the computing unit of a digital computer performs several processes, and the control problem, therefore, is to select the particular process to be performed. Control signals, one for each operation, control the switching circuits that perform the operations. Thus, the control signal for a particular operation will have the value *1* when that operation is to be performed and *0* otherwise.

A set of *N* control signals can be generated from a smaller number of signals. For instance, eight control signals develop from three *flip-flops* (Q^1, Q^2, and Q^3) feeding into triple *and* gates.

$$R^0 = \overline{Q}^1 \cdot \overline{Q}^2 \cdot \overline{Q}^3$$
$$R^1 = \overline{Q}^1 \cdot \overline{Q}^2 \cdot Q^3$$
$$R^2 = \overline{Q}^1 \cdot Q^2 \cdot \overline{Q}^3$$
$$R^3 = \overline{Q}^1 \cdot Q^2 \cdot Q^3$$
$$R^4 = Q^1 \cdot \overline{Q}^2 \cdot \overline{Q}^3$$
$$R^5 = Q^1 \cdot \overline{Q}^2 \cdot Q^3$$
$$R^6 = Q^1 \cdot Q^2 \cdot \overline{Q}^3$$
$$R^7 = Q^1 \cdot Q^2 \cdot Q^3$$

Each of the signals R^i has the value *1* only for one combination of the values of Q^1, Q^2, and Q^3. For example, the signal R^2, which is formed from signals $\overline{Q}^1$, Q^2, and $\overline{Q}^3$ by means of *and* gates, has the value *1* only when Q^1 is *0*, Q^2 is *1*, and Q^3 is *0*. For all other values of Q^1, Q^2, and Q^3, R^2 has the value *0*. These values of the *flip-flop* signal variables may be interpreted as digits of a binary number. The resulting numbers identify the control signals and the operations that these signals control.

The control numbers, when represented in the computer by discrete electrical signals, form the control signals for the operations to which they correspond. The list of control numbers, together with an identifying description, is called the "order

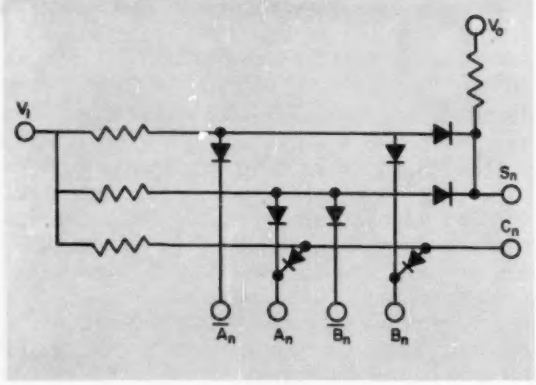

FIG. 6. This is the basic circuit for adding binary numbers. By adding a flip-flop circuit to the terminal C_n, the carry digit is handled automatically.

code", "instruction code" or "command code" of the computer. The term "instruction code" is preferred.

DIGITAL MEMORY DEVICES

Many types of memory devices are used in digital computers. Some of these include:

- acoustic delay lines, in which the storage of information consists of recirculating pulses of sound
- storage tubes, in which the information resides in the charge state of a dielectric material
- magnetic tapes, magnetic cores, and magnetic drums, in which information is stored in the magnetic charge of the material

Each of these devices contains characteristics subject to logical interpretation and use in computers. The physical properties of storage devices will be discussed in greater detail in a subsequent article in this series; only their logical properties will be considered at this time. The magnetic drum and the magnetic core, to be used as examples here, will be treated in this light.

The Magnetic Drum

A magnetic drum consists of a rotating cylinder coated with a permanent magnetic material. The state of magnetization of the material records the discrete electrical signals. Thus, for binary signals, only the two easily obtainable magnetization states need be used: saturation in one direction designates the *binary digit 0*, and saturation in the other direction designates the *binary digit 1*.

A magnetic head transducer records the computer signals by converting electrical signals into magnetic fields. The magnetic field saturates a small region of the drum during an elementary computer time. This small region is the recording space for one binary digit. The symbol M_n^j denotes the value of the digit recorded in this space. Here, the superscript j stands for the channel of the magnetic drum that is under consideration. The subscript n, an integer, defines the region of the channel. If the channel provides recording space for N binary digits, n extends from 0 to N-1.

The subscript n of the magnetic signal variable M_n^j may be put into correspondence with the subscripts of the signal variables of the switching circuits. Thus, in one case the subscript denotes the time, while in the other case it denotes the region in which the digit is recorded. However, since the time for the magnetic head to scan the region determines the extent of the region, the two subscripts can be identified if the regions of the magnetic drum channel are numbered so that the zero position passes the recording head at zero time. In addition, the subscript of the magnetic signal variable must be defined for n greater than N and less than zero—according to the following equation:

$$M_n^j = M_{n-N}^j$$

This equation holds only when new recording of signals is not taking place.

The recording of the signal A_n takes place under control of the signal W_n. Then the relationship of M_n^j and A_n is defined by the equation:

$$M_n^j = W_n \cdot A_n + \overline{W}_n \cdot M_{n-N}^j$$

This fundamental equation of the recording action of the magnetic drum is a difference equation in time, a characteristic of all memory devices.

The magnetic head serially scans the digits in one channel of the drum; but a drum usually has several channels and these may be scanned in parallel.

Magnetic Cores

An array of magnetic cores comprises another magnetic memory device. Here, each tiny magnetic core stores a signal corresponding to one binary digit. These cores connect together by wires that carry the electrical signals needed for recording or reading out the digital information. Because each magnetic core of the array is always accessible through these wires, the array serves as a particularly useful parallel access memory device.

PROGRAMMED AUTOMATIC DIGITAL COMPUTERS

For a computer to operate automatically, its control unit flip-flops must automatically change to a new instruction upon completion of the preceding computing operation. The instructions stored in the digital memory devices accomplish this easily, and when the flip-flops have changed their states, the arithmetic unit performs the new operation.

Each instruction specifies the nature of the operation to be performed (addition or multiplication, or a logical operation), where the numbers are to be found in the memory (that is, their memory addresses), and the memory address of the next instruction. Some of these memory addresses may be implied. The memory address scheme used in the instruction code classifies a computer.

A "single address" computer refers explicitly only to the memory address of one number. The other number used in the operation is assumed to have been placed previously into the arithmetic unit, and the instruction for the next operation is assumed to be located adjacent to the current instruction.

Although most of the digital computers that have been designed and built are general purpose computers, their instruction codes differ. The nature of these codes determines the types of problems they can handle efficiently. For instance, computers designed for scientific and engineering computation use codes that emphasize arithmetic operations, and those for processing business data use codes that emphasize data rearrangement and handling of alphabetical data.

A somewhat neglected area of computer development is the limited purpose computer. Here, the instruction code specifies only enough operations for a limited class of problems.

The logical organization of present day computers is comparatively primitive. Their instruction codes depend on simple analogies to manual data processing procedures. Study of computing methods may be expected to lead to the development of computers with instruction codes that will significantly increase computer performance without proportionately increasing complexity.

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ELDRED NELSON

Sixteen years after getting his BA in Physics from St. Olaf College in Minnesota, and 12 years after receiving his PhD in Theoretical Physics from the University of California at Berkeley, Dr. Eldred C. Nelson came to the Ramo-Wooldridge Corp. as associate director of its Computer Systems Div. Of those last 12 years, between 1942 and 1954, six were spent with Hughes Aircraft Co. as senior staff physicist, head of the Computer Systems Dept., head of the Advanced Electronics Laboratory, and associate director of Research & Development Laboratories. He remained at the university for about a year after receiving his doctorate to work in the Radiation Laboratory and instruct in physics, and in 1943 went to the Los Alamos Laboratory at Santa Fe, N. M., as group leader in the Theoretical Physics Div. This was followed by teaching stints at several universities and a year as a partner in a consulting firm.

BINARY

		AUGEND 0	AUGEND 1
		SUM	
ADDEND	0	0	1
	1	1	10

OCTAL

ADDEND \ AUGEND	0	1	2	3	4	5	6	7
	SUM							
0	0	1	2	3	4	5	6	7
1	1	2	3	4	5	6	7	10
2	2	3	4	5	6	7	10	11
3	3	4	5	6	7	10	11	12
4	4	5	6	7	10	11	12	13
5	5	6	7	10	11	12	13	14
6	6	7	10	11	12	13	14	15
7	7	10	11	12	13	14	15	16

A CORRECTION FOR BASIC DIGITAL NO. 2

This addition table was left out of the article, *Digital Computers Need Orderly Number Systems*, by Irwin S. Lerner, in our October issue. Please correct your copy in this manner:

1. Substitute this new table for Figure 2 in the article. Retain the old caption.
2. What was Figure 2—a table of numerical equivalents—now becomes Figure 1 in the article. The Figure 1 caption applies.
3. Disregard the multiplicand table that was wrongly inserted as Figure 1.

FOR:

the newcomer to control
the not-too-technical man
the expert who needs a refresher
a review of feedback principles shows . . .

How Stabilization Improves Closed-Loop Operation

GARETH M. DAVIDSON and LUTHER NASHMAN,
American Bosch Arma Corp., Arma Div.

With closed-loop theory and practice advancing at such a rapid pace, details often overshadow basics. This prompted CONTROL ENGINEERING to ask the authors for an article explaining the fundamental concepts of closed-loop control. Starting out with a non-mathematical review of stability, damping, and error, the article then lays the foundation, with a discussion of a positional servo, for a mathematical description of control systems. But the focal point of the article is stabilization. The following, all linked to this technique, are covered in this issue: detecting unstable systems by the frequency response method, correcting instability, and transient response. In a future article the authors will detail the techniques and circuits of stabilizing networks.

A closed-loop system automatically maintains its output equal to (or proportional to) its input. To accomplish this, an instantaneous output signal is fed back and compared with the desired input signal; any difference (error) existing between these signals drives the output until the error reduces to zero. A simple electromechanical closed-loop arrangement, shown in Figure 1, denotes input and output, amplifier, output actuator, negative feedback path, and comparator.

The basic operation has been simply stated. What must also be considered, however, are the relationships between kinetic (moving) and potential (stored) energy, and frictional forces. These play important parts in the dynamic performance of closed-loop systems. Three important and interrelated factors concerning performance are:

- Stability
- Damping
- Error

STABILITY

A system is stable if the output responding to a sustained input change ultimately steadies to a constant value. However, dynamic relationships between physical components may cause "lags" in the feedback path. When a lag is great enough, the feedback signal becomes positive, and if of sufficient magnitude, causes instability. Then, the output continuously oscillates in an uncontrolled manner, or drives to a limit and stays there. Unstable equipment is of little practical value. Therefore, it is essential that systems be designed and tested for stability. If an existing physical system, or one being designed, is unstable, corrective measures can provide stability. How to detect and eliminate instability will be the main concern here.

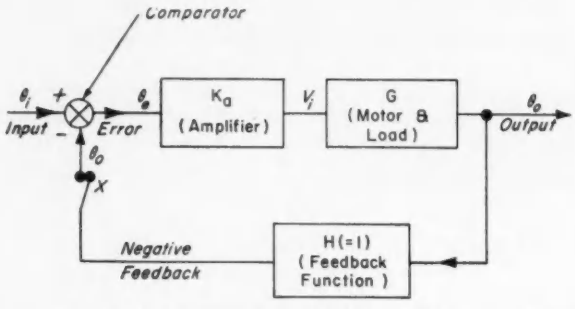


FIG. 1. A simple electromechanical closed-loop system includes the basic elements found in single-loop arrangements. Each of the elements (blocks) has a transfer function that specifies the output to input ratio. When the loop is closed, at x, the negative feedback signal helps the output closely follow the input command.

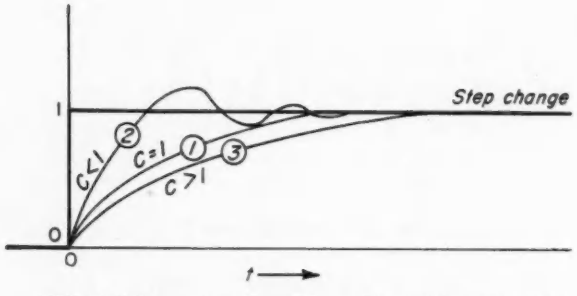


FIG. 2. When a step change (heavy lines) disturbs the input, the output will have a response in the time domain similar to one of the three curves. Whether the output is critically damped (1), underdamped (2), or overdamped (3), depends on the relationship of the physical parameters of the system. This relationship is called the relative damping factor, C.

DAMPING

If the system is stable, then its physical *damping* determines how fast, after being subjected to a *step-change input*, the output approaches its final value. Figure 2 shows three curves that represent relative degrees of damping. As will be seen later, *relative damping, C*, can be computed from the system parameters: *friction, inertia*, and *gain*. Usually the desired amount of damping may be obtained by adjusting the effective friction in the system.

Curve 1 shows critical damping ($C=1.0$). The output approaches its final value in the shortest time without overshooting. When *C is less than 1.0* (Curve 2) the system is underdamped and overshooting occurs, subsequently settling down to the final value. In engineering practice one or more overshoots are permissible, as the overall effect is to make the output reach the final value (as demanded by the input value) in the shortest time. At *C greater than 1.0* (Curve 3) the system is overdamped, and the error between the input and the output exists for a longer time than in either of the other cases.

In the special case of *C equal to zero* the system is absolutely unstable, and continuously oscillates at its *undamped resonant frequency*. Thus stability and damping are closely related. Although it is true, as will be shown mathematically, that increasing the *relative damping* improves stability, a criterion of a well-designed servo system is satisfactory stability without excessive damping.

ERROR

Error is the difference between input and output. Besides electrical and mechanical steady state errors in the components of the system, there is the error that arises from the dynamic operation of a closed loop system.

As an example of dynamic error, consider an electromechanical servo system designed to have the output follow the *position* of the input. If the input rotates at constant velocity, then in tending to make the output position correspond with the input, the output must also rotate at the same velocity. This requires power delivered to the output member, and that power is developed by applying a voltage to the input terminals of the amplifier. But the only way such a voltage can develop is from a difference, or error, between the input and output positions. The amount the output must lag behind the input is the error. It is proportional to velocity of rotation and to frictional forces, but inversely proportional to system gain.

It has been pointed out that damping, and therefore stability, depends on the frictional forces in the system. Since velocity error increases with friction, the problem is to introduce sufficient *effective* friction to assure stability and adequate damping, but not to increase the error. Fortunately, there are techniques to accomplish this. They, too, will be treated in a subsequent article.

BASIC MATHEMATICS

The preceding sections gave a word-picture of the physical operation of closed-loop systems. A mathematical portrait, however, facilitates better understanding, introduces techniques and terminology, and establishes basic relationships. A relatively simple system serves as an example.

A single-loop, closed-loop, positional servo is shown in Figure 1. Its function is to have an output position follow any arbitrary change in an input position. Each block in the system represents a physical device and is denoted by a symbol, such as *K, G, H*, etc.; the symbols designate *transfer functions*—the ratio of output signal to input signal. *Transfer functions* will be discussed after deriving the closed-loop equation.

The transfer functions in Figure 1 are:

$$V_i = \theta_e K_a \quad (1a)$$
$$\theta_o = V_i G \quad (1b)$$
$$\theta_f = \theta_o H \quad (1c)$$
$$\theta_e = \theta_i - \theta_f \quad (1d)$$

By combining the four basic equations, the closed-loop *transfer function* is derived:

$$\theta_o = V_i G = \theta_e K_a G = K_a G(\theta_i - \theta_f)$$
$$= K_a G(\theta_i - \theta_o H) = K_a G\theta_i - K_a GH\theta_o$$

Collecting terms containing Θ_o to the left side of the equation,

$$\theta_o + K_a GH\theta_o = K_a G\theta_i$$
$$\theta_o(1 + KGH) = K_a G\theta_i$$

and finally

$$\frac{\theta_o}{\theta_i} = \frac{K_a G}{1 + K_a GH} \quad (2)$$

The plus sign of Equation 2 means that the feedback signal is opposite in polarity to the input signal, which gives stabilizing negative feedback.

Transfer Functions

Equation 2 has been derived in terms of symbolic transfer functions: K, G, and H. However, each transfer function has a physical meaning. Two, K_a and G of Figure 1, will be derived.

The transfer function of the amplifier is the ratio of its output voltage to its input voltage. It is symbolized by K_a, a constant factor that does not vary with frequency of interest of the input signal. Therefore

$$K_a = \frac{V_i}{\theta_e}$$

where Θ_e is the error signal (volts) and V_i the output signal of the amplifier (volts). V_i is also the input to the motor.

The motor transfer function is more complex because it includes motor and load inertia (J) and friction (F). Actually, *elastance* should also be considered, but it can be assumed negligible in this case and set equal to zero. By setting the torque developed by the input voltage, V_i, equal to *inertia* and *friction* at the output, the *transfer function*, G, is obtained.

$$T = K_t V_i = J\alpha + F\omega_p \quad (3)$$

where K_t = torque constant of motor
ω_p = angular velocity, the rate of change of θ_o, the *angular position*
α = angular acceleration, or rate of change of ω_p
F = viscous friction of load, plus inherent damping in motor

Because position, Θ_o, is the output of interest, ω_p and α must be stated in terms of Θ_o:

$$\omega_p = \frac{d\theta_o}{dt} \quad \text{and} \quad \alpha = \frac{d^2\theta_o}{dt^2}$$

In an operational method, such as *Laplace transform* $\frac{d}{dt} = s$; $\frac{d^2}{dt^2} = s^2$, and incidentally, $\int \ldots dt = \frac{1}{s}$; $\iint \ldots dt\,dt = 1/s^2$ These expressions are true for quiescent conditions. That is, there is no stored energy: all parts are at rest. Mathematically, this is known as *initial conditions zero*.

By using s, Equation 3 can be handled in algebraic form. Rewriting the equation in terms of s,

$$K_t V_i = Js^2\theta_o + Fs\theta_o = s(Js + F)\theta_o$$

The transfer function of the motor (angle of rotation per volt input) is:

$$G(s) = \frac{\theta_o}{V_i}(s) = \frac{K_t}{s(Js + F)}$$

Assuming H equals 1, the case for direct feedback, the *closed-loop transfer function is*, therefore:

$$\frac{\theta_o}{\theta_i}(s) = \frac{K_a G}{1 + K_a G}(s) = \frac{K/J}{s^2 + (F/J)s + K/J} \quad (4)$$

where $K = K_a K_t$.

The denominator of Equation 4 contains the pertinent information regarding stability and damping of the system. This information may be obtained either in the *time-domain* or in the *frequency-domain*. Although in different frames of reference, the two domains are related by the *Laplace transformation*. Both are useful in representing the behavior of closed-loop systems. Both the *frequency-domain* and the *time-domain* will be discussed as separate entities, with some physical correlation uniting the two domains. *Laplace transformation* is discussed in a separate section.

TIME DOMAIN

Investigation of the denominator of Equation 4 helps reveal the response in the time domain. The denominator, set equal to zero, is called the *characteristic equation*, and its *roots*, using the *Laplace transform*, determine the possible transient *modes*. That is, whether the output will be critically *damped*, *underdamped* (damped oscillations), or *overdamped*.

The two *roots* of $s^2 + (F/J)s + K/J = 0$ are found by the quadratic formula:

$$r_1, r_2 = \frac{-F/J \pm \sqrt{(F/J)^2 - 4K/J}}{2}$$
$$= -\frac{F}{2J} \pm \frac{\sqrt{F^2 - 4KJ}}{2} \quad (5)$$

The denominator of Equation 4 can be put in more suitable form, relating the response to the relative damping factor, C, and the *undamped resonant frequency*, ω_o:

$$s^2 + 2C\omega_o s + \omega_o^2 = 0$$

where $\omega_o = \sqrt{K/J}$ and $C = \frac{F}{2\sqrt{KJ}}$ (6)

The three *modes* of response depend on the magnitude of F^2 compared with $4KJ$. Shown in Table 1 are the possible root combinations of Equation 6, and corresponding graphs in time (functions of relative damping, C). The output curves are in response to a *unit step change input*, and are obtained by the *inverse Laplace transform*.

If the order, n, of the *characteristic equation* ($s^n + a_{n-1}s^{n-1} \ldots + a_o = 0$) is higher than 2, determining the n roots becomes more involved and

LAPLACE TRANSFORMATION

Conversion from *time domain* to *frequency domain* is made by the *Laplace transform*, and conversely, from *frequency domain* to *time domain* by inverse transformation. The *Laplace transform* is defined by

$$F(s) \triangleq \mathcal{L}(t)$$

where $F(s)$ is a function of s
s equals $j\omega$, for steady-state conditions
$\mathcal{L}$ means the transform integral, and
$f(t)$ is a function of time.

$$F(s) = \mathcal{L}f(t) = \int_0^\infty f(t)e^{-st}\,dt$$

The exponential decay function, $e^{-\alpha t}$, occurs frequently in nature. The transform here is

$$F(s) = \int_0^\infty e^{-\alpha t}e^{-st}\,dt = \int_0^\infty e^{-(s+\alpha)t}\,dt$$

$$= \left[-\frac{1}{s+\alpha}e^{-(s+\alpha)t}\right]_{t=\infty} - \left[-\frac{1}{s+\alpha}e^{-(s+\alpha)t}\right]_{t=0}$$

$$= 0 + \frac{1}{s+\alpha} = \frac{1}{s+\alpha}$$

The transform can then be set up in a table:

Transform Pairs

$F(s)$	$f(t)$
$\frac{1}{s+\alpha}$	$e^{-\alpha t}$
$\frac{\omega}{s^2+\omega^2}$	$\sin \omega t$
$\frac{s}{s^2+\omega^2}$	$\cos \omega t$
$\frac{1}{s^2}$	t
s	1

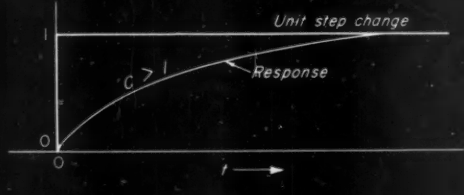
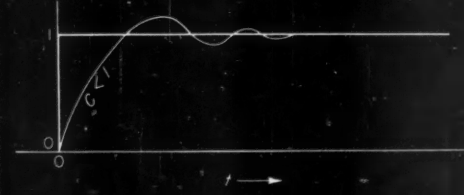
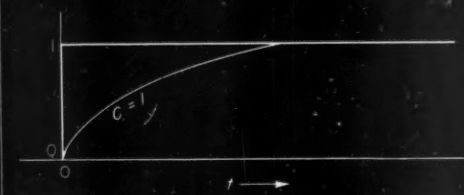
In the case of critical damping, $C = 1$, the characteristic equation is

$$F(s) = \frac{1}{(s+\omega_o C)(s+\omega_o C)} \quad \text{and} \quad f(t) = te^{-\omega_o t}$$

This curve is plotted in Table 1.

In dealing with a transfer function in terms of $F(s)$, the time domain input signal, $f(t)$, must also be converted to its $F(s)$. For instance, a unit step change input has $f(t) = 1$. Converting by the Laplace transform gives $F(s) = s$.

TABLE 1

$C = \frac{F}{2\sqrt{KJ}}$	ROOTS $s^2 + 2C\omega_0 s + \omega_0^2 = 0$	TRANSIENT RESPONSE TO UNIT STEP CHANGE
OVERDAMPED $C > 1$	$r_1 = -\omega_0 C + \omega_0\sqrt{C^2-1}$ $r_2 = -\omega_0 C - \omega_0\sqrt{C^2-1}$	
UNDERDAMPED $C < 1$	$r_1 = -\omega_0 C + j\omega_0\sqrt{1-C^2}$ $r_2 = -\omega_0 C - j\omega_0\sqrt{1-C^2}$	
CRITICALLY DAMPED $C = 1$	$r_1 = -\omega_0 C$ $r_2 = -\omega_0 C$	

often exceedingly difficult. Since systems operate over a period of time, their performance in the *time-domain* (transient response) becomes the final criterion. When the feedback loop of a stable system has been closed (x in Figure 1) transient tests are made by introducing an input disturbance (signal) and observing the output response. One of the common input signals is the *step change*, as shown in Table 1.

FREQUENCY RESPONSE

However, analysis in the frequency domain gives information about stability not readily obtained from the time domain. Frequency analysis procedures are easier to handle and aid in synthesis of corrective networks. The big advantage of the frequency response method is that stability information can be obtained directly from the *open loop transfer function, KGH*.

Let H again equal 1. For the previous case:

$$KG(s) = \frac{K_a K_t}{s(Js + F)} \tag{7}$$

If $T_m = J/F$ and $K_m = K_t/F$, Equation 7 becomes

$$KG(s) = \frac{K_a K_m}{s(T_m s + 1)} \tag{7a}$$

For frequency analysis, s becomes $j\omega$ where ω is the input signal frequency. Therefore,

$$KG(j\omega) = \frac{K_a K_m}{j\omega(T_m j\omega + 1)} \tag{8}$$

Equation 8 is a function of frequency, ω, and at each frequency can be represented by a vector; that is, it has a *magnitude* and *phase angle*. The *loci* of the tips of the vectors, as ω goes from zero to infinity, are plotted on polar coordinate paper.

Nyquist's stability criterion (for single-loop systems) states that if the loci contour encloses the point $1\angle -180$ deg, the system is unstable. Conversely, if the point is not enclosed, the system is stable. In the stable case, the greater the distance between the curve and the point, the greater will be the margin of stability of the closed-loop system. Both a stable and an unstable system are plotted in Figure 3. *Phase margin* and *gain margin* measure relative stability.

Phase Margin and Gain Margin

Phase margin is the angular difference between the 180 deg axis and the angle at which the magnitude of the KG ($j\omega$) equals unity. This angle is taken as negative when measured clockwise from the zero deg axis. Therefore, stable systems will have a positive *phase margin*, unstable systems, zero or negative *phase margins*. As a general rule, the greater the positive *phase margin* of the open-loop transfer function the greater the system's stability.

As evidenced by Figure 3, as *gain* increases, so does the tendency toward instability. The relative

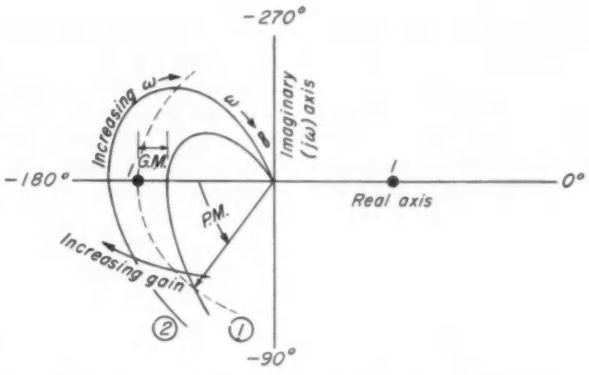


FIG. 3. Typical Nyquist plots of an open-loop transfer function, KG, useful in determining the relative stability of a closed-loop system. Because the system is third-order (at high frequency), the curves asymptotically approach the minus 270 deg axis as the magnitude falls to zero. Curve 1 represents a stable system—it does not enclose the $1\angle -180$ deg point. Curve 2 shows instability—it encloses the point. Phase margin (PM) and gain margin (GM) show relative stability—both are positive. However, when gain increases, they become negative and the system is unstable.

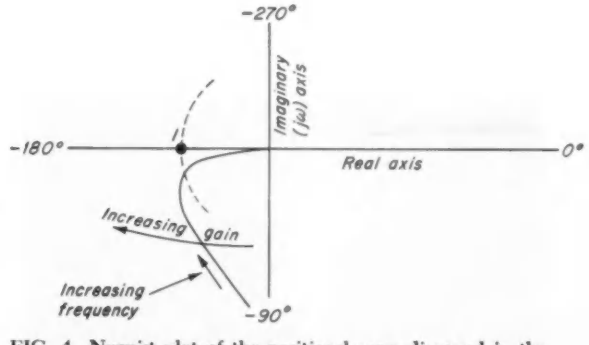


FIG. 4. Nyquist plot of the positional servo discussed in the text and represented by Equation 8. Since the system is second-order the curve approaches the minus 180 deg axis, and no amount of increased gain can cause the contour to enclose the $1\angle -180$ deg point.

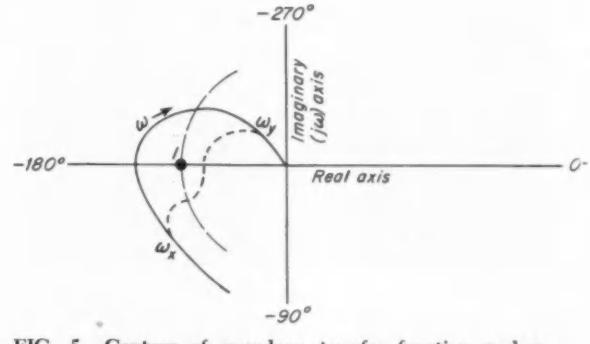


FIG. 5. Contour of open-loop transfer function encloses $1\angle -180$ deg point—the system is unstable. However, with a corrective network, effective in the region of frequencies from ω_x to ω_y, the contour of the system reshapes so as not to enclose the point and stability is assured.

freedom from instability is measured by the *gain margin*. This latter is the difference between a *unit vector* (gain equals unity) and the output vector magnitude of the open-loop transfer function as it passes through the minus 180 deg axis. A stable system will have this output magnitude less than unity. *Gain margin* indicates how much the gain can be increased before sustained oscillations take place. If the gain (Curve 1 in Figure 3) were made to exceed unity, as in Curve 2, the system would become unstable.

The polar plots in Figure 3 do not represent the positional servo system previously discussed. Figure 4 typifies the open-loop response of this system. It will be noted that this mathematical system can never become unstable—no amount of increased gain can cause the contour to encircle the $1\angle -180$ deg point.

In Figure 3 the contour *asymptotically* approaches the minus 270 deg axis as ω reaches infinity. The contour of the positional servo, Figure 4, approaches minus 180 deg as ω approaches infinity. The reason

CONSTRUCTION OF BODE DIAGRAMS

The advantages of Bode diagrams in the frequency domain are:

- Transfer functions can be approximated by straight line segments. The segments are asymptotic to the actual response.
- The diagram can be constructed by inspection of the factored form of the transfer function, as in Equation 8. Each term has line segments.
- The overall function can be obtained by adding separately the magnitudes and the phase shifts of the individual functions.

The magnitudes are plotted on log-log graph paper, and the phase shifts on linear coordinates against log frequency.

Consider the term $(1 + j\omega T)$. The magnitude and phase shift at any ω can be found by trigonometric solution of a right triangle. Magnitude equals

$$[1^2 + (\omega T)^2]^{1/2} \text{ and}$$

the phase shift equals

$$\arctan \frac{\omega T}{1}$$

When ωT equals unity magnitude equals 1.414 (3 db) and the phase shift equals 45 deg. The frequency at which ωT equals unity is called the "break" frequency.

For simplicity, the term may be approximated by two line segments that are asymptotes of the actual magnitude. Below the break frequency the line is horizontal; above, it rises at 20 db/decade. A decade is a ten to one ratio of frequency. The phase shift is zero deg at ω equals zero, plus 45 deg at the break frequency, and plus 90 deg at infinite ω.

Terms of the form

$$\frac{1}{1 + j\omega T}$$

can be handled in a similar matter, but are inverse. That is, the phase shifts are negative and the magnitude falls off at *minus* 20 db/decade. Plotted in Figure 6 are the individual magnitudes and phase shifts of the terms in transfer function:

$$KG = \frac{K(1 + j\omega T_2)}{j\omega(1 + j\omega T_1)} \quad \text{where} \quad T_1 > T_2$$

The phase shift of the overall transfer function of Figure 6 approaches minus 90 deg at high ω. Therefore, the closed loop system cannot be unstable. However, added transfer functions containing $j\omega$ terms in the denominator may cause instability.

Since transfer functions are represented by straight line segments, the correcting functions can also be represented this way. Segments designating corrective networks or devices, or shifts to indicate change gain, are added to the overall transfer function so that the modified function is stable. The frequency range, ω_x to ω_y, in which the correction is required, can be easily determined from the plot.

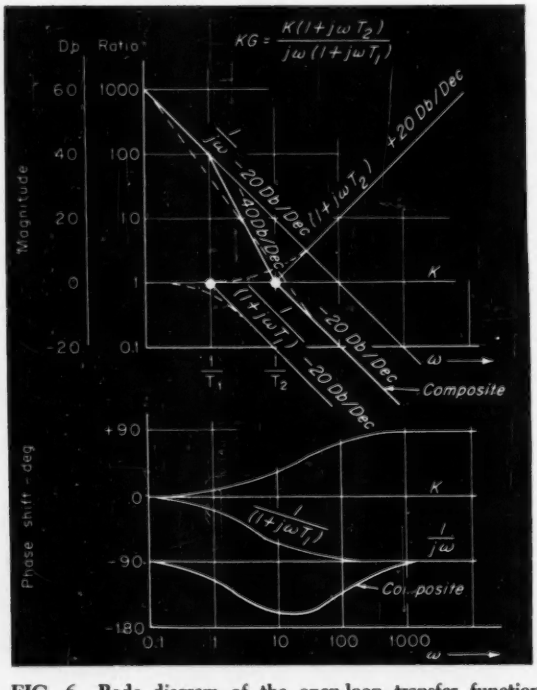


FIG. 6. Bode diagram of the open-loop transfer function, KG, shows magnitude and phase shift of the individual terms in the function. Adding the individual line segments produces the composite response for KG (heavy lines). Solid lines indicate approximate (asymptotic) response of the terms while the dashed lines represent the true response.

for this difference is that the open-loop transfer function for Figure 4 has two $j\omega$ terms in its denominator, while that for Figure 3 has three $j\omega$ terms:

$$\frac{1}{j\omega(1+j\omega T_1)(1+j\omega T_2)}$$

When a system is accurately analyzed mathematically, its performance can be predicted. However, the physical components of systems frequently include phenomena such as short time lags and non-linearities, that may be difficult to determine, and rigorous description of a system in terms of accurate transfer functions becomes burdensome. These effects have been omitted from the transfer function in the present case. Seemingly trivial, when combined they increase the complexity and order of the physical system. Thus the positional servo is mathematically stable in terms of *assumed transfer functions* only. Actually, this system might be third- or fourth-order, making it potentially unstable.

CORRECTING UNSTABLE SYSTEMS

The open-loop transfer function, plotted as vector *loci* on polar coordinate graph paper, indicates instability when the contour encloses the $1\angle -180$ deg point. Obviously, if the feedback loop were closed, the system would be unusable.

Therefore, it becomes necessary to correct, or reshape, the contour. A third-order unstable system is shown by heavy lines in Figure 5. A reshaped locus, assuring stability, is indicated by dashed lines. Both the *phase margin* and the *gain margin* are now positive.

Reshaping the contour can be accomplished in several ways. Basically, correction consists of modifying the open-loop transfer function, KGH, in the region ω_x to ω_y (Figure 5). Correction can be made on individual transfer functions in these ways:

- Reduce the gain, K_a. This allows KGH to retain the same shape, but shrinks the contour.
- Modify the physical parameters of the G transfer function; for example, increase the friction coefficient, F. This is shown by dashed line in Figure 5.
- Introduce a new transfer function, K_1G_1, having a frequency response between ω_x and ω_y that corrects the overall loop response of $KGHK_1G_1$.

Corrective action is usually a compromise. For instance, if K_a is reduced, the usable output power, or torque, is also reduced. If G or H are modified, then K_a may have to be increased to compensate for consequent loss in the corrective network.

BODE DIAGRAM

The Bode diagram makes it easier to study the combination of new or modified transfer functions, and their overall effect. Involved is simply a different set of coordinates, which represent another way of plotting the frequency response characteristics of individual blocks. (See box.)

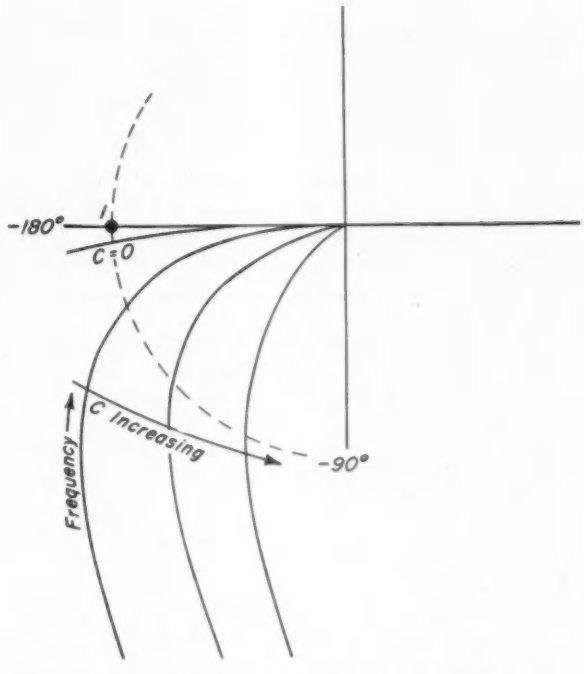


FIG. 7. As the relative damping factor C, increases, the phase margin also increases. Therefore, the heavier the damping the greater the stability.

IMPROVED DAMPING

After a servo has been designed and proved stable, the real criterion is its response to sudden disturbances at the input (and output). The response depends on the *relative damping factor*, C, where $C = \frac{F}{2\sqrt{KJ}}$ and F is the viscous friction coefficient. If the response is not suitably damped for the application, adjustment in C can be made by varying F, the friction coefficient.

Frictional forces are of three kinds: *static, coulomb, or viscous. Static friction* is a discontinuous force. It is independent of the output force until this force reaches sufficient magnitude to "break" the static friction. *Coulomb friction* is constant. *Viscous friction* is proportional to velocity of the output member. Here the frictional force equals $F\omega_p$, as in the positional servo.

A change in C to improve damping also affects the contour in the frequency domain. If the transfer function of Equation 7 is plotted in terms of increasing C, Figure 7 results. As C increases, the system becomes more damped in the time-domain,

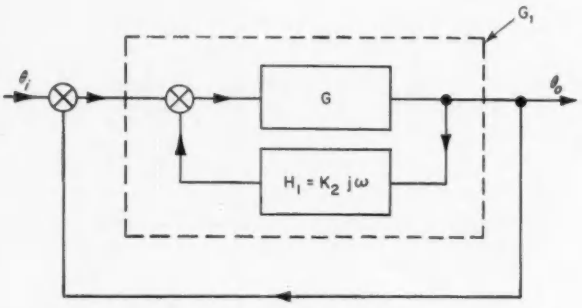


FIG. 8. Addition of a subsidiary feedback loop gives signal proportional to velocity of output position. The new open-loop transfer function, Equation 9, shows how the effective friction increases with this method of improving damping.

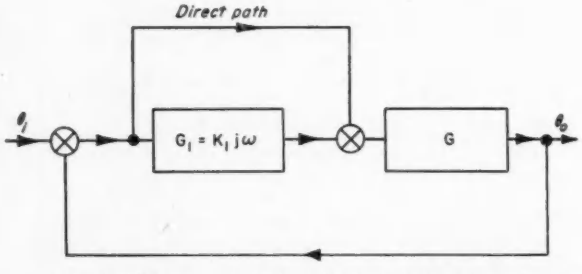


FIG. 9. Adding error-rate damping in the through loop results in new transfer function, Equation 10, which gives increased damping without increasing velocity error.

with the *phase margin* also increasing. Therefore, the heavier the damping, the greater the stability.

Mechanical *viscous friction*, such as a dashpot, has several shortcomings, particularly when more is required to obtain desired damping: it wastes power and increases velocity error. Electrical devices increase the effective coefficient of friction, but not the wasted power.

One way to improve damping is by feeding back a voltage, H_1, proportional to the velocity of the output member. The path of this voltage is distinct from the direct feedback path. Here H_1 becomes $K_2 j\omega$ and the new open-loop transfer function is:

$$KG_1(j\omega) = \frac{K_a K_t}{j\omega(Jj\omega + F')} \qquad (9)$$

where $F' = F + K_2 K_a K_t$

This increases the effective friction without increasing the energy dissipation of the system. However, it also increases the velocity error. Figure 8 shows the new feedback arrangement.

To improve stability and damping, but to minimize velocity error, another scheme may be used. *Error-rate* damping, Figure 9, introduces a voltage, K_1G_1, shunted by a direct feedback path, in the through loop of the system. K_1G_1 (or $K_1 j\omega$) produces a voltage proportional to the rate of change of the difference $\Theta_i - \Theta_o$. Mathematically, this results in a new open-loop transfer function

$$KG = \frac{(1 + K_1 j\omega)(K_a K_t)}{j\omega(Jj\omega + F)} \qquad (10)$$

Note there is now a $j\omega$ term in the numerator. With the introduction of this "phase lead", the overall "phase lag" decreases and the *phase margin* of the servo increases (improving stability and damping) without any corresponding increase in velocity error.

CORRELATING FREQUENCY AND TIME

The *closed-loop transfer function* has been examined in the *time domain*. And the open-loop, which determines closed-loop operation, in the *frequency domain*. It may be assumed, therefore, that some correlation exists between the two domains. They are related by the relative *damping factor*, C, and the *undamped resonant frequency*, ω_o.

Figure 10 shows the amplitude of the closed-loop transfer function plotted against ω for various values of C. The peak value for each curve equals $\frac{1}{2C\sqrt{1-C^2}}$ and occurs at frequency $\omega_n = \omega_o\sqrt{1-2C^2}$. ω_n is the *damped natural resonant frequency*. Since the closed-loop response and the relative damping both depend on C, the curves indicate typical responses to *transient input*. A peak amplitude of 1.2 to 1.6 in the closed-loop frequency response generally provides satisfactory speed of response and overshoot in the time domain.

REFERENCE

This is by no means an extensive treatment of the theory and practice of closed-loop control. If your appetite has been whetted by this non-rigorous condensation, read Prof. T. J. Higgins's excellent source articles, "Basic Books For Your Control Engineering Library", in Control Engineering: "Industrial Process Control", November, 1954, and "Servomechanisms", December, 1954.

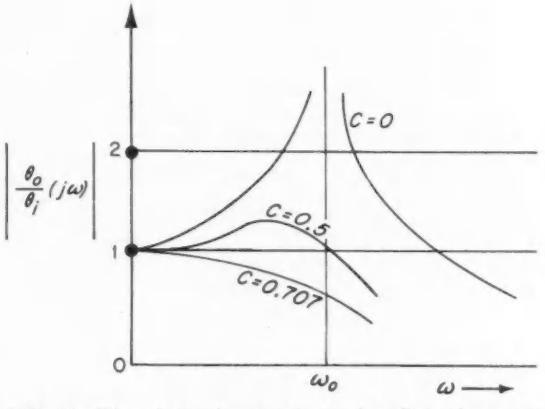


FIG. 10. The relative damping factor also affects the magnitude of response of a closed loop system. Thus, peak magnitude and time-domain responses have some correlation.

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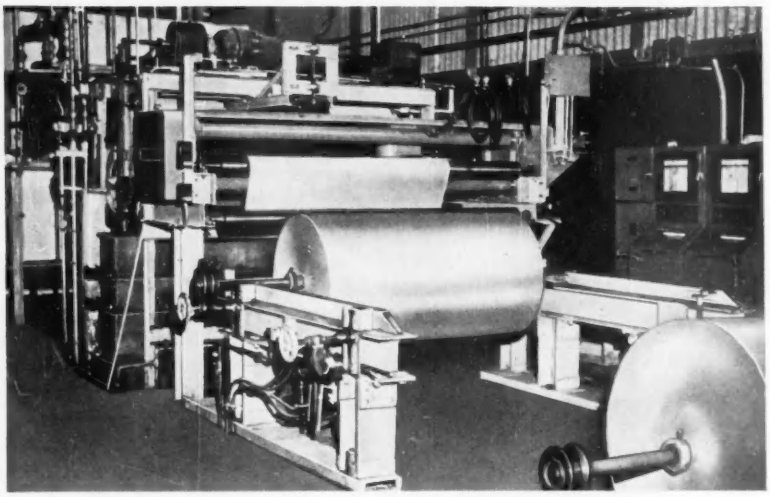
IDEAS AT WORK

Computers Team with Nuclear Gages to Control a Paper Saturating Process

The picture at the right shows most of the essentials of a new, progress-packed industrial control system. Installed in Formica Co.'s plant in Cincinnati, it regulates the impregnation of kraft paper with phenolic resin to within 1 per cent by weight. Involved: two beta ray weight gages and two analog computers cascaded to bring in coating weight per cent and average weight across the sheet.



Input end of the treater. In the center the sheet is passing through the beta ray scanner. Recording, computing, controlling, and monitoring units are in the console.

By J. D. COCHRANE, JR., and LOUIS STAUBITZ, Formica Co., and W. E. VAN HORNE, Industrial Nucleonics Corp.

Simple, special-purpose analog computors have an assured future in process control—particularly in cases where product characteristics that can not be measured directly must be computed from measurements of two or more dependent variables. This situation is common in the paper converting field, where coatings or saturants are added to paper. The object is to control the weight of the coating or saturant applied, regardless of variations in the basis weight of the paper. While it is impossible to measure the weight of coating alone, it is possible to gage the weight of the uncoated paper and the weight of the coated paper. A two-variable computer can then subtract uncoated from coated weight for absolute magnitude of coating. Or the one variable can be divided by the other for ratio of coating to total weight.

THE SPECIFIC PROBLEM

At the Formica plant in Cincinnati, the process to be controlled is the impregnation of kraft paper with phenolic resin. This paper is later cut into sheets, laminated in several thicknesses with a decorative top sheet or "liner", and cured in the press to form Formica laminated plastics. For good lamination, the percentage of resin weight to total weight must be controlled precisely: insufficient resin means improper bonding, too much resin means edge flow in the press and an inferior product.

In Formica's impregnators, paper is unrolled and passed first through a "dip tank" full of liquid resin, then through scraper bars where the excess is wiped off. The longer it is immersed, the more resin it absorbs.

The biggest problem in controlling an impregnator is the fibrous quality of the paper, a non-homogeneous material. The basis weight and absorbency of paper can vary along the length of the roll as well as across the sheet. These variations must be compensated for by positioning the dip roll.

To achieve true feedback control of a saturater, then, it is necessary to continuously measure resin percentage in the treated paper, and in such a way that side to side variations are averaged out. This measurement is used to actuate an automatic controller that drives a motor to raise or lower the roll, as required.

ELEMENTS OF THE CONTROL SYSTEM

A system to do the complete control job was designed and built for Formica by The Industrial Nucleonics Corp. The basic measurements are made by two of this company's beta ray gages—the isotope sources being mounted below the sheet and the detectors above. To show profile weight across the sheet, the gages are made to scan continuously from side to side. The scanning drive starts the unit at one edge and moves slowly across the sheet. At the opposite side of the paper the gages shut off and return at high speed to start the cycle again. Hence the profile shown on the recorder chart is always drawn in the same direction.

In operation the scanning drives are synchronized so that both gages are at the same distance from the edge at all times. Signals are taken from the two recorder pens and fed into an analog computer to secure ratio of resin weight to total weight and record this on a second strip

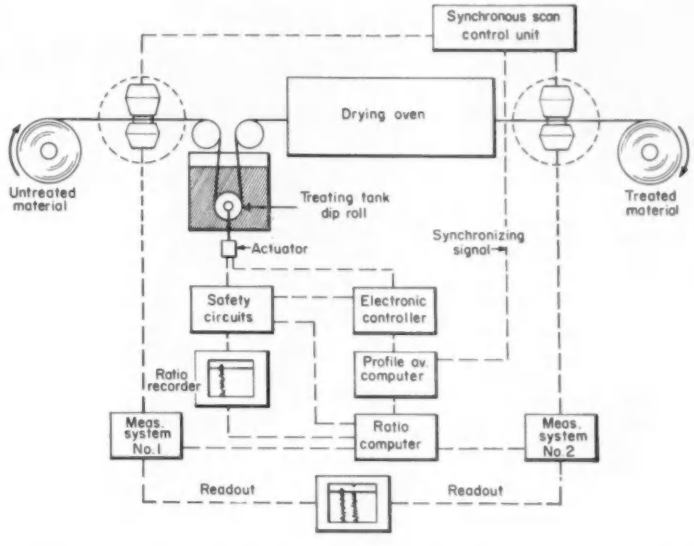
chart. The mathematical function is described as:

$$Z = \frac{X - Y}{X} \times 100\%$$

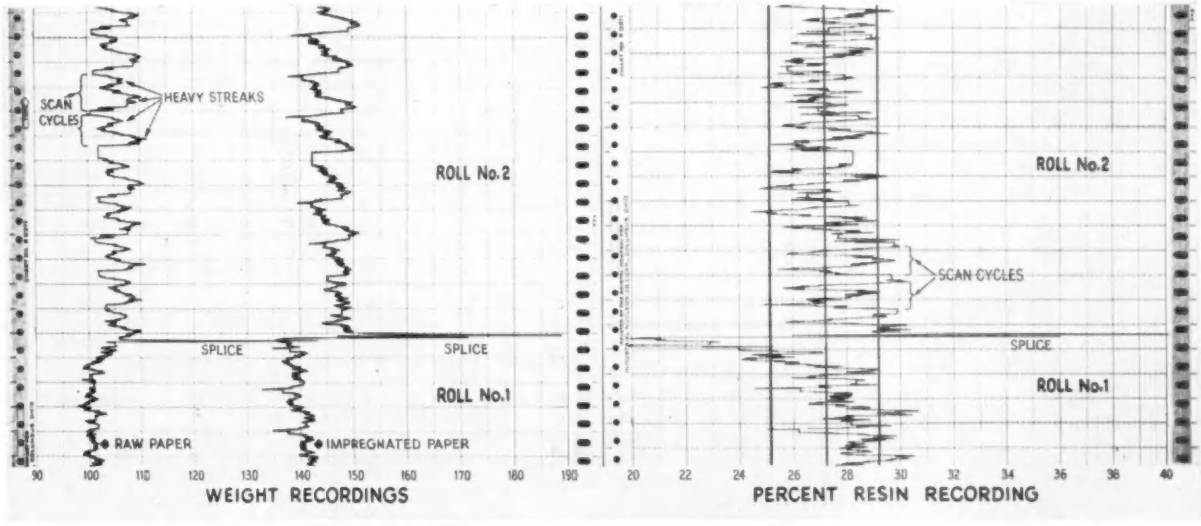
Where: Z is the resin ratio in per cent; X is the total weight of the treated stock; Y is the untreated paper weight.

While the computer recorder boldly shows percentage of resin in the sheet at each point across the web, this is not enough to allow continuous control. Another computation must be made for average ratio, since the dip roll, of course, affects impregnation across the entire sheet.

An integrating computer averages the resin ratio across each scan cycle. If this average is not at the control point, the electronic controller proportionately signals a motor, which then drives the dip roll to a new position. Since in this installation the transportation lag through the oven is much less than the scan time, the controller can act at the end of each scan cycle. If the lag were greater, it would be necessary to de-energize the controller long enough to permit each correction to be felt at the dry end before another correction is initiated.



THE CONTROL SYSTEM: In the block diagram the first gage measures the weight of the dry, untreated paper as it comes from the reel. The second gage measures the total weight of the impregnated sheet, which includes both paper and resin. The two weights are recorded side by side on a two-pen recorder. The measured information also feeds into the ratio computer and the resultant point-to-point ratio is averaged by an integrating computer, which supplies the control signal through an electronic controller. Tied in monitor and safety circuits throw the system into manual if elements fail.



INTERPRETING THE CHART RECORD

Above is a reproduction of recorder charts taken at the end of one roll of paper and the beginning of the next. The trace on the left of the dual chart shows the basis weight of the untreated paper. The single recorder chart shows the percentage of resin. Each scan cycle can be identified by the short vertical line drawn by the pens as the gages are shut off between the end of one scan and the start of another. The serious upset caused by the difference in paper characteristics can be seen. The first roll has good profile and it displays excellent absorbency characteristics. The second roll, however, is significantly heavier, and is characterized by two heavy streaks, one on each side of the center of the sheet. In spite of the upset, it can be seen that the automatic controller maintained the average resin within tolerance.

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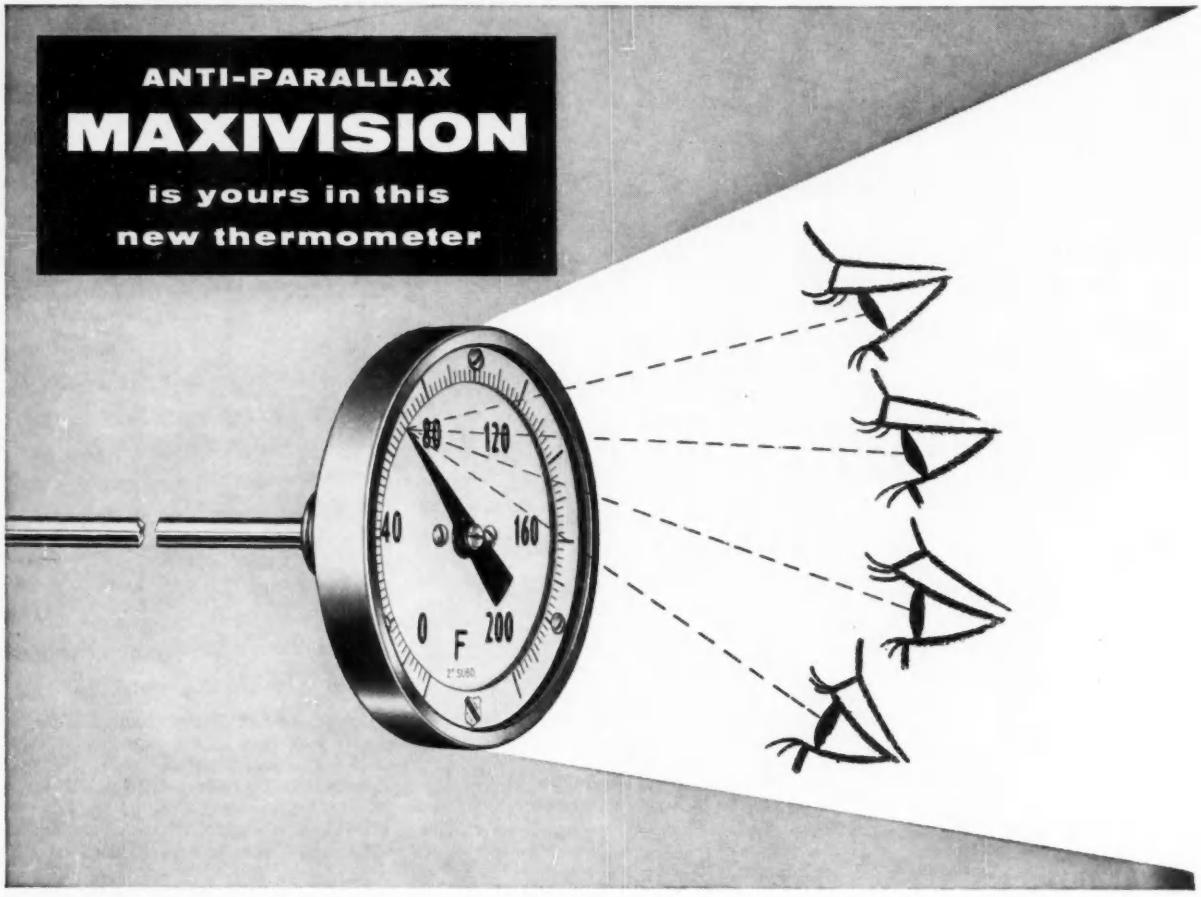

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Stem: 18-8 stainless steel, mirror polished. All joints welded. Resists corrosion. Provides strong, rigid and tight closure against process pressures. Lengths: 2½" to 24".

Connection: Fixed, ½" N. P. T.

Separable Sockets: Available for use in closed systems or where measured medium is corrosive to the stainless steel stem. Fit over all standard stem lengths except 2½".

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TWO IDEAS FOR USERS OF CONTACTOR SERVOS:

1. "Make" Contactor Servos

Many engineers shy away from contactor servos because of the severe practical limitations of contact life, radio noise, large dead area, and excessive arcing at the contacts. Here's a circuit for an ac contactor servo which eliminates most of these undesirable limitations.

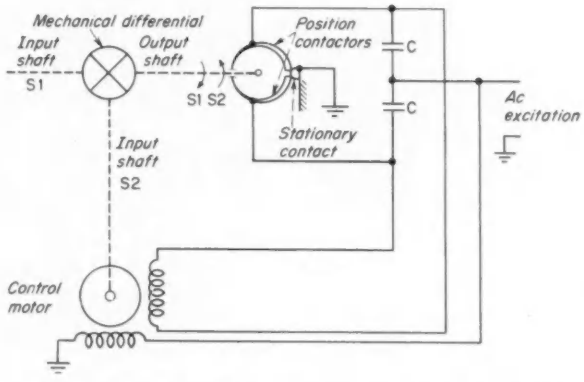

FIG. 1 Ac contactor servo nulls on contact "make" rather than "break". At null, both sides of motor field are grounded. Off null, current flows through a series capacitor.

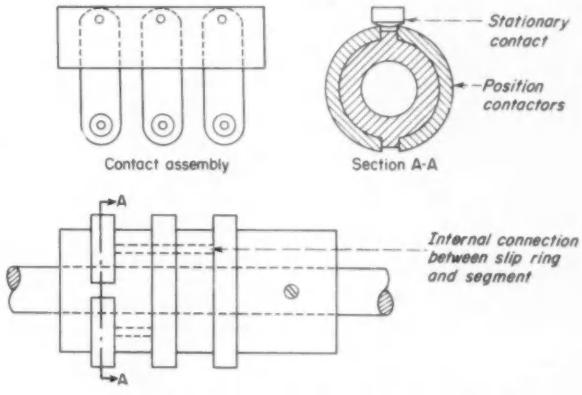

FIG. 2 Mechanical design of contactor for servo described here. Second contact, adjustable about 180 deg point, can control dead space.

D. V. SPRIGGS, Servomechanisms, Inc.

The input data to a contactor servo is a mechanical shaft rotation that unbalances the null or zero error condition. When the servo unbalances, the control motor drives until the output shaft rotation equals the input shaft rotation. The details of how the mechanical shafts are arranged depends upon the application.

Figure 1 shows a schematic for an ac contactor servo that controls one phase of a two-phase motor. The circuit illustrates the null condition when the stationary contact shorts both position contactors. A command input shaft rotation displaces the position contactors from the null position, unshorting one of the output contactors from ground potential. This action switches a capacitor in series with the control motor winding and causes an ac current to flow in one direction through the motor winding. If the stationary contact contacts the other position contactor only, a capacitor is again in series with the control motor winding and an ac current flows in the opposite direction through the motor winding. Proper wiring of the control motor winding and selection of capacitors will cause the control motor to run in a direction towards the null position.

SOME ADVANTAGES

The "make" switching operation that occurs when the servo approaches null improves the more common "break" for the following reasons: There is never a condition when an inductive current is broken, because the control motor winding is shorted when the motor stops. A small arc takes place when the stationary contact leaves one position contactor, but it will be much less than the arc produced by opening a series-resonated capacitor and motor winding. This reduced arc increases contact life and decreases radio noise interference compared to other contactor circuits.

When the servo reaches the null condition, the control motor winding is shorted. This produces some dynamic braking, reducing the coasting distance of the motor armature. Any decrease in coasting distance of the motor armature increases the theoretical accuracy of the servo by allowing a smaller dead area (area at null where an input shaft rotation will not cause the motor to operate). The braking action also improves the stability for a given dead area.

The circuit of Figure 1 is particularly suited to ac motors with unbalanced windings. The winding drawing the most current can be permanently connected across the line. Thus the higher impedance winding can be controlled by the contactors, decreasing the size of the tuning capacitors and the current controlled by the contacts to increase contact life.

Figure 2 shows the mechanical details of one possible application of the circuit. The unit has three silver slip rings and mating contact. One slip ring is cut into two equal segments

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The famous Univac® of Remington Rand has widened still further its lead over other electronic business computing systems. Univac is still the *only* completely self-checked system . . . the only one which can read, write, and compute simultaneously without extra equipment. And now, the Univac II adds to these superior features the speed of a magnetic-core memory.

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ELECTRONIC COMPUTER DEPARTMENT **Remington Rand** ROOM 2235, 315 FOURTH AVENUE, NEW YORK 10, N. Y.
DIVISION OF SPERRY RAND CORPORATION

electrically isolated from each other. Internal silver strips connect the segments to their respective uncut slip rings. Care must be taken to remove the burrs from the edge of the cut or the contact life may be reduced.

DEAD SPACE CONTROL

The stationary contact controlling the servo is curved opposite to that of the segment (A-A, Figure 2). This technique allows for a very small dead area because the dead area is a function of the overlap between the position contactors and the stationary contact. If more dead area is required for stability, an additional stationary contact, electrically isolated, may be added 180 deg away from the first contact and aligned slightly off center. Thus dead area can be increased without hand filing each contactor.

In applying this circuit with standard servomotors and standard supply voltages, care must be taken with the circuit values. In a series-resonated circuit where the voltage across the reactive components is 90 deg out of phase with the line, the actual value of this reactive voltage equals the line voltage times the Q of the circuit (which now is the motor winding Q). The Q of the motor winding in a servomotor is usually slightly greater than unity, which may cause the actual voltage across the motor winding to be higher than the design value. This condition can be remedied by adding a resistor in series with the contactor arm to ground, decreasing the circuit Q and thus decreasing the voltage across the motor winding. Detailed analysis of the circuit indicates that for a purely reactive component of voltage across the motor winding with respect to the excitation voltage, and balanced motor torque:

$$X_C = X_L + \frac{r + 2R}{Q}$$

where X_C = reactance of tuning capacitor C
Q = Q of the motor winding
X_L = inductive reactance of the motor winding
r = ac resistance of the motor winding
R = resistance of added resistor, if required

2. Lower Static Error in Contactor Servos

Contactor servos have advantages in simplicity and inexpensive power amplification over proportional servos. A special function potentiometer can add the virtues of proportional action in the dead space.

In a conventional contactor servo, current is supplied by the error-sensing contacts to one side or the other of a split motor field or to one or the other of oppositely rotated electric clutches. See column A in Figure 2. In such a servo the error must exceed the contact spacing before motor current can flow. And then, full motor current is applied suddenly. The gap length and, therefore, the servo's dead space are generally determined by servo accuracy requirements, and are limited on the low end by load inertia and friction and other damping in the system. This system can come to rest anywhere in the dead space and can have a static position error up to half the gap length.

In the case of a contactor servo where the error is electrical and a relay is used for the contactor, the relay can be "dithered" by feedback or external injection at a frequency relatively high compared to signal frequencies. The motor integrates the effect of the dither frequency, and if opposite relay contacts close for equal times, it centers in the gap. The error signal is added to the dither signal to cause the relay to spend more time on one contact than the other. Thus, the dead space in a contactor servo can be proportionalized to eliminate static position error.

To use the same technique in a mechanical contactor servo, where the outside contacts are on the load shaft and the center contact is the input (a simpler setup than the electrical), the dither would have to be introduced mechanically on the input shaft. This is not convenient and is probably impractical.

A better idea is to use a special potentiometer in place of the contactor. This potentiometer should have the output function shown in Figure 1 (one is commercially available from Computer Instruments Corp.). Electrically, it remains at one end or the other of its range except for three degrees (mechanically) in the center where a linear resistance change of up to 10,000 ohms takes place. The ends of this three-degree segment act like the gap in the ordinary contactor. The linear resistance change in between means proportional servo action within this "gap", Figure 2B.

Some small static error still remains due to the torque necessary to overcome static friction in the potentiometer. Because this torque is about 0.1 in.-oz and the stalled motor torque can be 2 to 4 in.-oz, the system's torque amplification is 20- or 40-to-1.

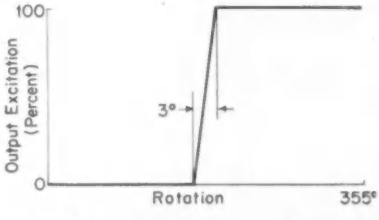

FIG. 1 Output vs. shaft rotation for potentiometer to replace contactor in mechanical input contactor servo.

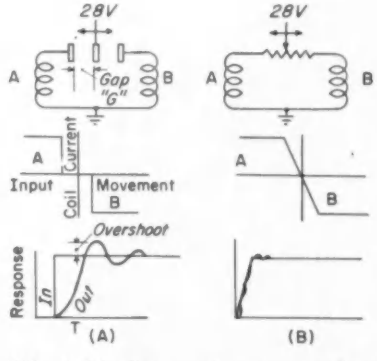

FIG. 2 Circuit, current vs. error, and response for (A) conventional contactor servo, and (B) special potentiometer (contactor) servo.

Type 9 motor-driven induction generator driving two Type 11CT synchros through gear train having ratio of 1500:1. Slip clutch operates to permit one control transformer to be rotated when second control transformer has shaft restrained by stops. Cams close 2 switches during specified degrees of synchro rotation.

big control problem . . . small servo solution

Despite its small size and extreme compactness, this Transicoil plug-in servo assembly always "does the job right". That's because it was especially designed for a single application . . . by a company whose major function is solving individual servo control problems with complete, precisely engineered and manufactured servo assemblies.

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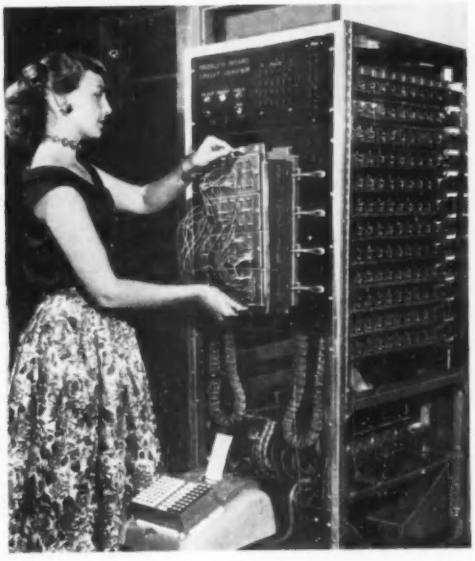
Verifier Prints Out Patchcord Locations

The managers of large electronic computing facilities have learned that the greatest single source of error is the human operator. This knowledge has led to efforts in two directions: to relieve the human operator of many routine tasks, and to check these tasks after they have been completed. The verifier described here is a result of the latter effort. It is applicable to computers whose operational elements are interconnected on a detachable plugboard by means of patchcords, the plugboard being removed from the computer for wiring and checking. The verifier catches errors in patching, tracks down non-conducting patchcords (broken wires, high contact resistance, cold soldered joints), and through a printed record of its patchboard connections, "stores" problems for future runs.



WOLFGANG G. BRAUN and L. MILTON WARSHAWSKY

Wright Air Development Center, Ohio

The basic idea of a plugboard verifier is simple. It rapidly scans the wired plugboard and prints pairs of numbers. These numbers indicate those pairs of pins that are connected by patchcords.

THE CODING SYSTEM

This report is based on the development of a prototype verifier at work on REAC plugboards. Actually, this particular board, with its 528 pins, is not large enough to warrant such a device. But boards with 1,500 to 3,000 pins can really put it to good use.

The REAC board is composed of 24 Winchester plugs, arranged in six columns four plugs deep. Each plug has 22 pins (Figure 1).

A four-digit code identifies the pins. The first two digits represent the plug number by row and column, the third and fourth digits the pin number. Thus, the first digit will read 1, 2, 3, or 4, the second digit 1, 2, 3, 4, 5, or 6, the third digit 0, 1, or 2 and the fourth digit any number between 0 and 9. For example, an entry on the printed list of

2413 1502

means that pin number 13 on the plug in the second row, fourth column is connected to pin number 2 on the plug in the first row, fifth column.

THE SCANNING OPERATION

A wired plugboard is placed on the patchbay of the verifier (identical to the patchbay of a REAC), a button is pushed, and the scanning action starts. This operation energizes one pin at a time, in consecutive order,

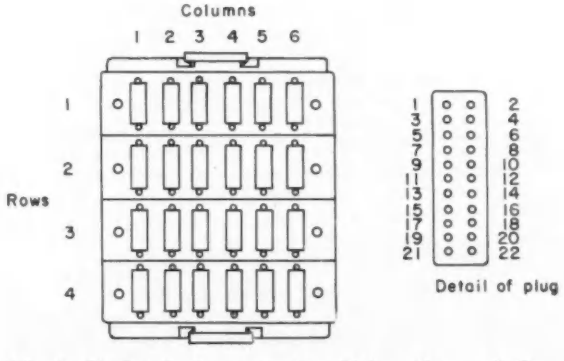


FIG. 1. Plugboard of computer for which verifier was built.

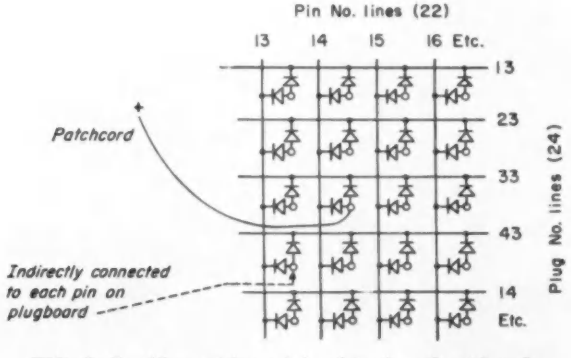


FIG. 2. Rectifier matrix used for detection of patchcords.

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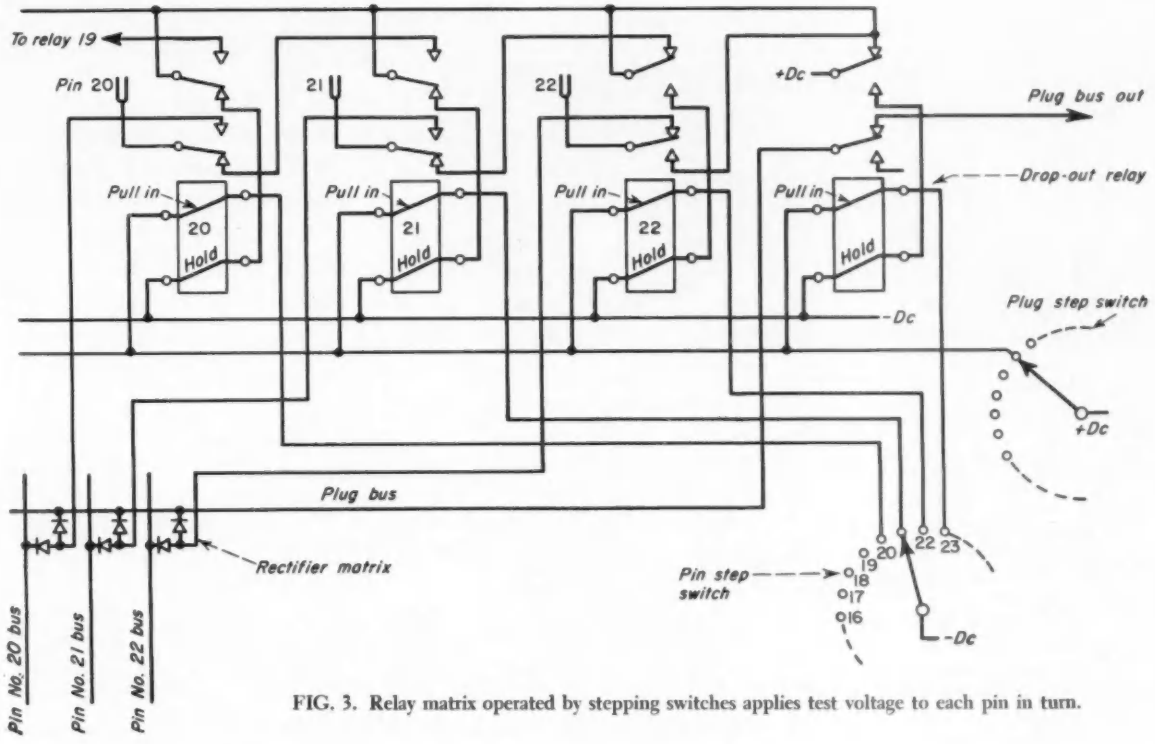


FIG. 3. Relay matrix operated by stepping switches applies test voltage to each pin in turn.

with a positive test voltage from a pair of stepping switches. One switch is associated with the 24 plugs, the other selecting pins of one plug.

If a patchcord is encountered as the individual pins are scanned, the test voltage will appear at some other pin. When this happens, the scanning stops until the addresses of the two pins involved are stored in the keyboard of the printer. Then, while the printing cycle takes place, the scanning is resumed. Only if the next patchcord is found before the printer is clear again, does the scanning wait for the completion of the printing cycle, which takes about half a second.

RECTIFIER MATRIX SPOTS PINS

The test voltage, which is applied to a pin through a patchcord (therefore a patchcord connection) is detected by a matrix of rectifiers (Figure 2). Two voltages will appear for that connection, one on a line identifying the plug number (33 in the figure) and the other on a pin number line (14 in the figure). Continuity is indicated immediately, as are the "coordinates" of the pin contacted. Selenium rectifiers can be used.

It is necessary to disconnect each pin in turn from the rectifier matrix and energize it with the test voltage. After the pin has been scanned it is not reconnected to the rectifier matrix, thus avoiding the double printing of each patchcord.

THE RELAY MATRIX

This switching is performed by double pole double throw relays having two separate windings, one of which, when energized, pulls in the armature, while the other, when energized, holds it in. The circuit for these relays is shown in Figure 3.

There are 23 (22 plus one drop-out) relays per plug, or a total of 552 in the verifier. In Figure 3, relay 21 is pulled in as its pull-in coil is energized. Relay 20, which was previously pulled in, is held by its "hold" coil. Note that pin 20 is disconnected from the matrix and the test voltage and that pin 21 is disconnected from the rectifier matrix and connected to the test voltage, and that pin 22 is connected to the rectifier matrix.

As the pin scanning proceeds through one plug, the current required to supply the holding coils increases in steps. And it would continue to increase as the scanning proceeds to the following plugs until all 528 holding coils are drawing power from the power supply unless something is done about it. The drop-out relay is the "something". This relay, which is energized when the pin stepping switch reaches its 23rd position, opens the plus dc supply to the holding coils, releasing all the armatures. This connects all the pins back to their corresponding rectifiers. But the corresponding plug number bus of the rectifier matrix is opened by a second set of contacts, thus effectively putting all the pins of the particular plug "out of the game".

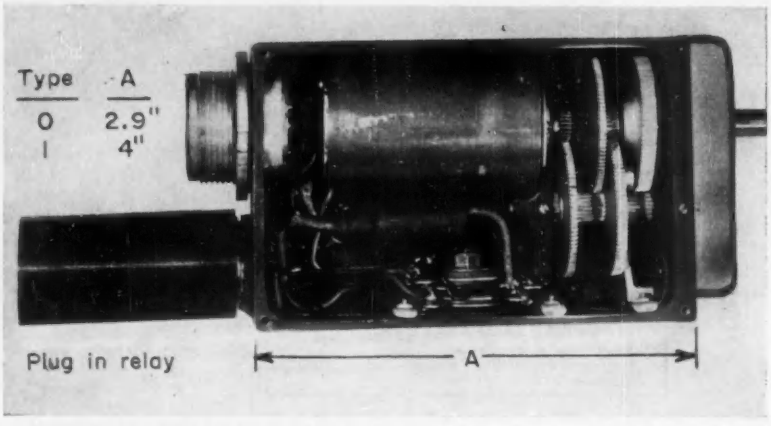
THE PRINTER CODING SCHEME

The printer is a standard 11-column adding machine (with the addition element removed) equipped with key actuating solenoids. A short pulse to the "add" solenoid causes printing and paper advance. Only eight columns of the printer are used.

Information for the first four digits comes from the stepping switches and for the second four digits from the rectifier matrix after a patchcord is encountered.

The average time for the preparation of the list of connections encountered on a 528-pin board is two minutes. This results from the verifier's free scanning rate of about 5 points per sec. The rate can be increased fivefold without any basic design changes.

NEW PRODUCTS



LISTING IN GROUPS

1- 4 Designs of the Month
5- 8 Servo Components
9-19 Indicators & Testers
20-28 Switches, Relays, Timers
29-34 Control Valves
35-44 Pulse Products
45-51 Some Detectors
52-61 Assorted Components

MINIATURE SERVOS use dithering-relay amplifier to obtain positioning power

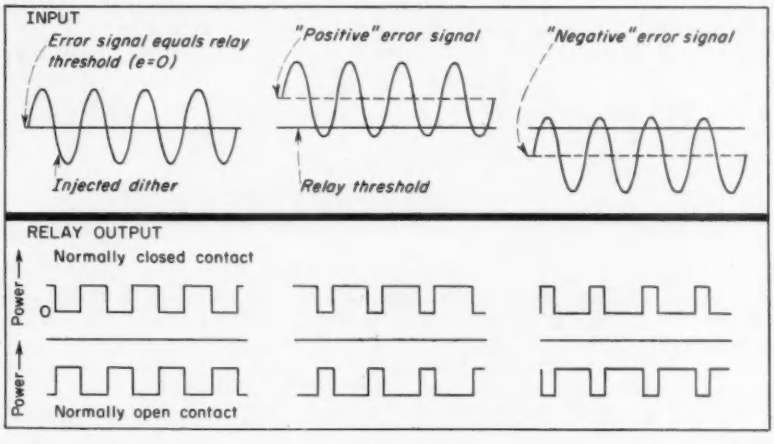
The soap-cake sized actuator above is a miniature servomechanism designed for use with high-impedance output radio control receivers. A linear motion model (1 in. sq by 5 in. long) is also available. Each contains a three-stage amplifier, a feedback pot, a small servo motor, and a gear train.

The extremely low power consumption, small size, and light weight of these devices contrast strikingly with their substantial physical outputs and make them appropriate for the operation of control surfaces in light aircraft or mobile equipment. Prices range from $98 to $150.

As seen in the schematic, lower right, the instrument's amplifier has two miniature tubes in its first two stages, the third being a relay. This relay is not used as a simple on-off controller. If it were, the servo would be subject to constant, rather large oscillations, with subsequent overheating of the motor and high power drain.

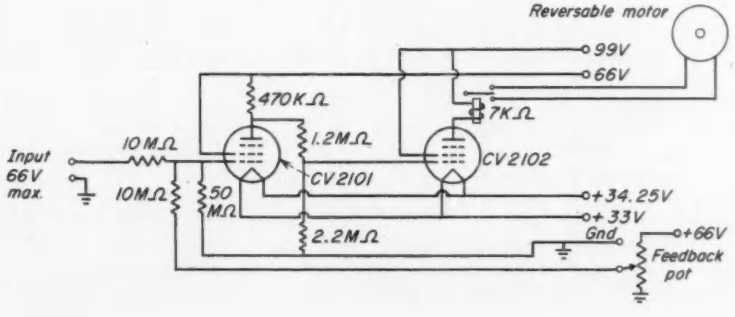
One way of avoiding this involves the use of a center-stable relay, but designers of these actuators were not able to find a suitable one. A center-stable arrangement implies maximum gain on both sides of a dead zone. Oscillations set up as the result of a step command signal die out at a rate proportional to the damping of the actuator and the width of the dead zone; yet accuracy and speed of response demand that both of these be as small as possible.

The servo shown here uses a conventional relay to obtain an infinitely narrow dead zone plus an output proportional to input. This is the result of an oscillating signal superimposed on the input signal. When the servo error is zero, the error signal is just a little too weak to close the relay. But the superimposed "dither" signal is enough to do the job. Hence, when the error is zero, the armature oscillates at the dither frequency (50 cps for these instruments), spending only a small fraction of its time on each contact.



The diagram at the upper right shows how deviations of the error signal cause one contact to be closed more than the other. In this way, the amplitude-variable error signal is converted into a pulse-width controlled signal. The inertia of the motor smooths out the power in these pulses to a continuous function.

The amplitude of the dither oscillation can determine the "gain" (or, more accurately, the proportional band)



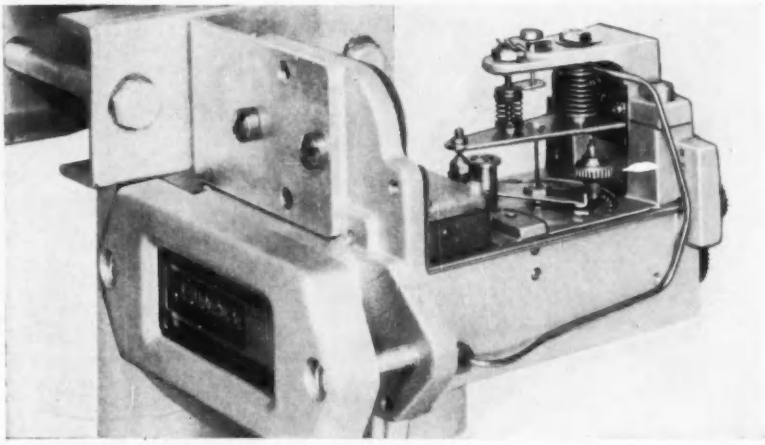
of this stage of amplification. When the dither is at a value equal to the maximum error signal, the relay will have a power output roughly linear through the entire range of the error signal. As the dither signal amplitude approaches the relay's actuation differential, the relay begins to operate like a center-stable relay if the error signal has a wide enough range).

Three convenient ways of causing oscillation in the relays are: (1) putting a second coil and set of contacts on the relay, causing this coil and contact set to operate in doorbell fashion; (2) feeding back to the input part of the negative (normally open contact) output of the relay so that the doorbell scheme works through the main contacts; (3) causing some element before the servo to inject the proper oscillation right on the command signal. Any of these techniques can be used with these servos.

The linear motion model (called a Push-Pull Servo by the maker) exerts up to 3 lb stalled and has a full travel of 1 in. in less than ½ sec. It weighs less than 5 oz.

Rotary models displaying output of 50 deg in under ½ sec have a stalled torque of 1 lb-ft for the Type 0 servo and 4 lb-ft for the Type 1. Powe. consumption is 10 watts maximum, idling draw of well under 1 watt. Accuracy for the servos without loads is 0.1 per cent. With a load of 50 per cent of maximum output, an error of 1 to 2 per cent full scale appears. Maximum repeatability error is less than 0.2 per cent. A 10 per cent change in plate supply affects current in the relay by an amount equivalent to only 0.1 per cent change in the input. *Harvey Electronics, Ltd., Farnborough Road, Farnborough, Hants, England.*

Circle No. 1 on reply card



MINIATURE TURBINE, controlled by centrifugal-governor, integrates square root of input signal.

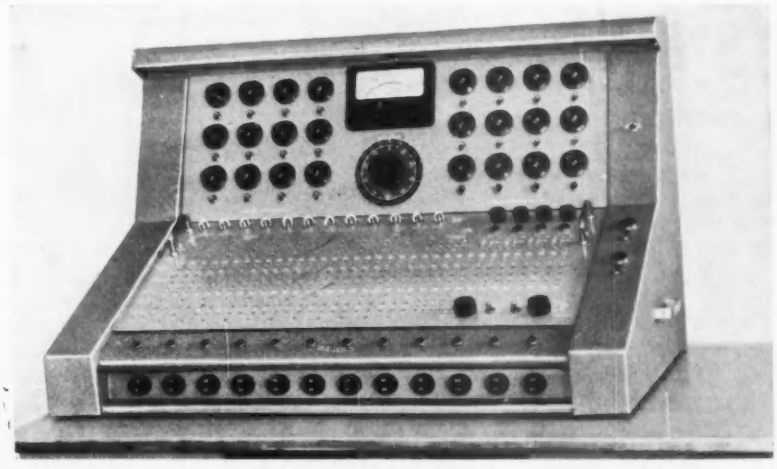
The flow integrator above does not require cams for square-root extraction. Accurate to within ½ per cent, the little machine integrates flow rates as indicated by a 3 to 15 psi signal from a differential pressure transmitter. This signal, applied through a bellows, positions a force bar in relation to a nozzle. The resulting back pressure at the nozzle, amplified by an air relay, regulates a jet of air onto the blades of a turbine wheel. The wheel is the unique feature here. As it revolves, the centrifugal force of a weight on its shaft is fed back to the bar to balance the measurement signal. In other words, the speed of the wheel is determined by a governor whose setpoint is established by the input signal. The centrifigal action operates according to the square of the wheel's speed, so that its rpm represents the square root of the bar's position. A counter on the shaft of the turbine indicates the flow integration. Gears are easily changed for various flow units. *The Foxboro Co., Foxboro, Mass.*

Circle No. 2 on reply card

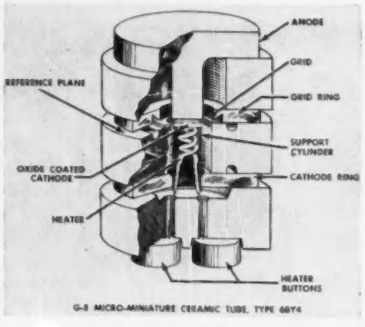
DESK MODEL ANALOG COMPUTER light enough to be carried.

This CSI Analog Computer, used in the analysis of autopilots, stability augmenters, electronic amplifiers, and hydraulic, pneumatic, and sampled data servo systems, contains 12 operational amplifiers, six integrating capacitors, 20 coefficient pots, eight variable voltages referred to ground, and four variable "floating" voltages. A special drawer contains fixed-value plug-in impedances, diodes, capacitors, and plug cords. The dc gain of the amplifiers is greater than 3×10^4 and power output 100 v into a 10 k ohm load. *Control Specialists, Inc., 115 E. Arbor Vitae, Inglewood 1, Calif.*

Circle No. 3 on reply card



NO GLARE, little gas permits high heat, low noise



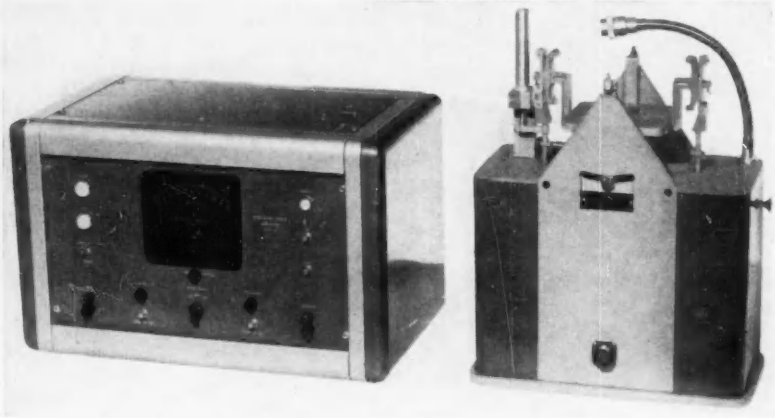
Circle No. **4** on reply card

The hardy little tube to the left, says GE, will operate at temperatures up to 1,000 deg. The miniature construction of the 6BY4 provides low induction connections to the plate and low internal capacitance for operation at frequencies up to 1,000 megacycles. The alternate ceramic and metal construction is made possible by a new metal-to-ceramic sealing process. The plate and most of the tube's metal parts are titantium, a metal that shows extremely high gettering (gas absorbing) characteristics. Despite its tiny size, the tube can be assembled automatically. The low noise factor promises it a future in high speed computers, TV tuners and uhf amplifiers. Its bandwidth at 900 megacycles is 10 mc. *General Electric Co., Schenectady 5, N. Y.*

Characteristics

Size.....½ in. by ⅜ in. diam
Filament.....6.3 v
Plate voltage.....200 v
Power gain.....15 db
Transconductance.....6,000 Micromhos
Amplification factor.....100

SERVO COMPONENTS



SIMULATION TABLE for flight control systems

The machine above is a single degree of freedom roll table for simulating angular displacement of gyros and accelerometers. It features a threshold of less than 5 microradians and a natural frequency of over 15 cps. Its operation in conjunction with analog computers permits on-the-ground "flight testing" of a complete aircraft or missile stabilization system. Input signal sources can be a computer, tape recorder, low frequency function generator, or digital-to-analog converter. *Micro Gee Products, Inc., Box 1005, 6100 W. Slauson Ave., Culver City, Calif.*

Circle No. **5** on reply card

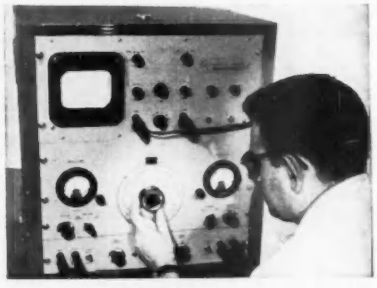
KIT for computer or simulator experimentation.

Neatly encased at the right is a comprehensive set of precision mechanical components for servo breadboards or electromechanical simulation. The three available sizes are for use in industrial or university laboratories. Hangers, gears, shafts, bases, leadscrews, indicators and even wrenches are included in some models. *Servomechanisms, Inc., 625 Main St., Westbury, L. I., N. Y.*

Circle No. **6** on reply card

SCOPE indicates performance of servo systems.

The Servoscope, a gain and phase-shift measurement instrument for servo systems, now is available with a cathode ray indicator. The little instrument provides sinusoidal, sinusoidal modulation in a suppressed carrier envelope, or square wave patterns. Four models offer frequencies from 0.001 to 60 cps. *Servo Corp. of America, 20-20 Jericho Turnpike, New Hyde Park, L. I., N. Y.*

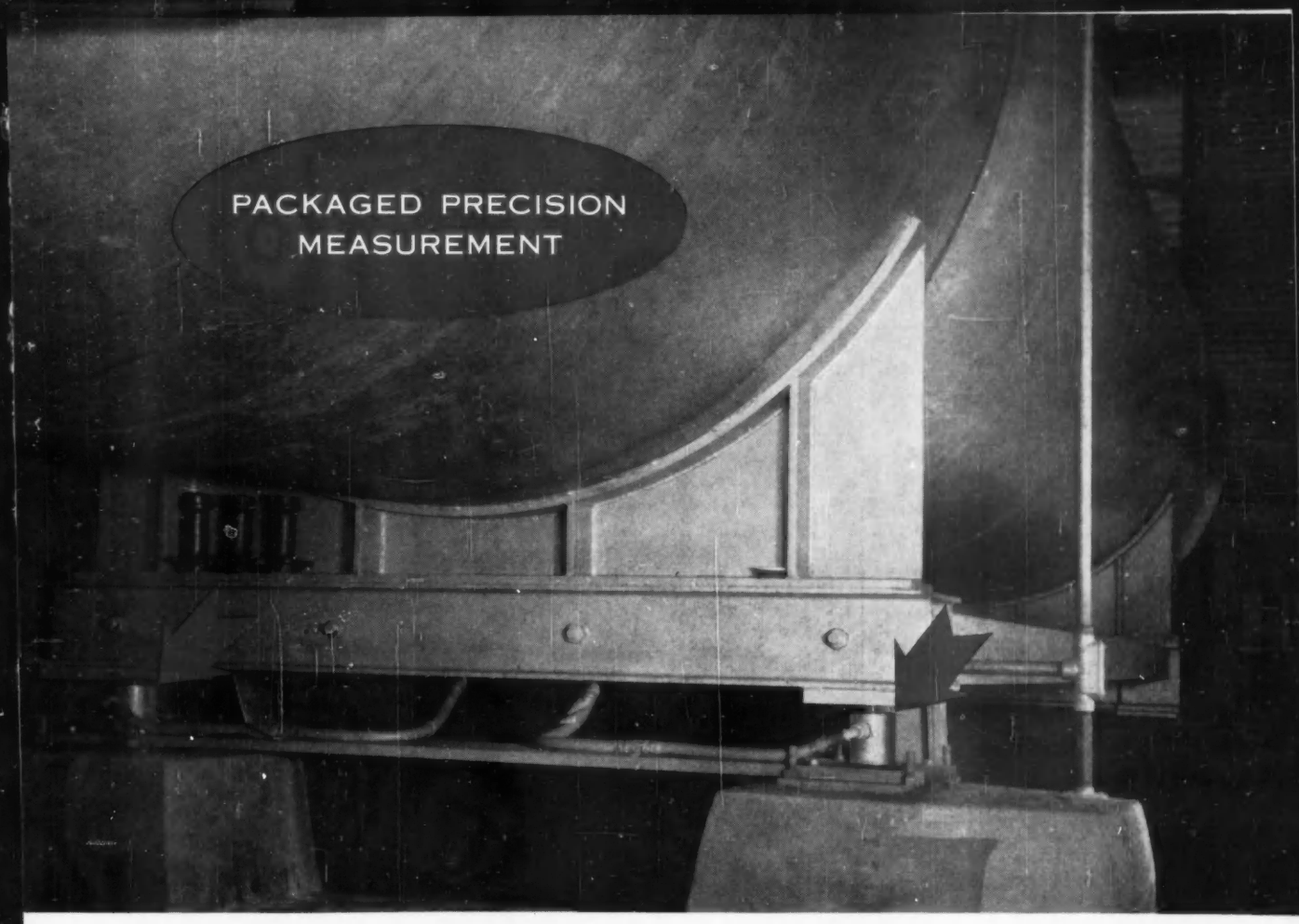


Circle No. **7** on reply card

INTEGRATING amplifier sums currents for computers.

The AIL Type 40 Integrating Amplifier is a four-tube electronic integrator for analog computers. All tubes are pre-aged and critical circuits hermetically sealed. Storage capacitors of 0.01, 0.04, or 0.05 mf may be charged. Sensitivity is 100, 25, or 20 v output per microcoulomb input. Output is 1 ma max. current at any output voltage from minus 100 to plus 100 v. *Airborne Instruments Laboratory, Inc., 160 Old Country Rd., Mineola, N. Y.*

Circle No. **8** on reply card



Stanley Home Products, Inc. checks Freon losses as

Two tiny SR-4® Load Cells weigh 200,000 lb. tanks automatically

Baldwin's "Packaged Precision Measurement," neatly solved the handling of large volumes of Freon at the Stanley Home Products plant in Easthampton, Mass. A constant record of stored and used quantities was needed to avoid excessive leakage and evaporation losses.

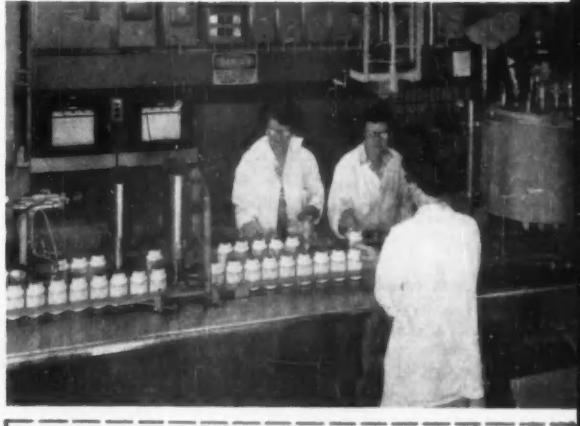
Continuous automatic weighing of their two 15,000 gallon storage tanks with Baldwin SR-4 Load Cells answered Stanley's problem perfectly. Two small SR-4 compression-type 50,000 lb. load cells were installed as supporting members on the concrete base at one end of each tank. These support exactly half the load of the 200,000 lb. tanks and the instruments are calibrated to read only the weight of the Freon in the storage tanks.

Reinforced flexible hose at inlet and outlet eliminates effect of connecting piping on weighing accuracy.

This Baldwin system gives Stanley weighing accuracy within ½ of 1% of scale (200,000 lbs.). Baldwin-engineered instrumentation provides remote indicators at the tank car siding and recorders at a centralized control panel. The weighing system controls a motor-driven pump at the siding, shutting it down automatically when the tanks have 13,500 gallons of Freon.

Packaged Precision Measurement can solve similar problems for *you*. For detailed information on SR-4 Device applications and instrumentation use coupon today.

Baldwin strip chart recorders on wall (lower photo) show rate of consumption of Freon. Recorders are connected by electrical cables to SR-4 Load Cells under one end of 15,000 gallon tanks on other side of wall (upper photo).



Eddystone Division

BALDWIN - LIMA - HAMILTON

Dept. 3365
Baldwin-Lima-Hamilton Corp.
Philadelphia 42, Pa.
(In Canada: Peacock Bros., Ltd., Montreal, Quebec)

Please send me the following new literature

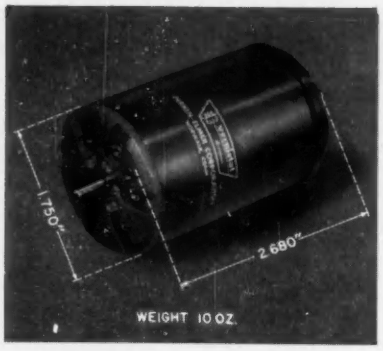
- ☐ Bulletin 4300 (Introduction to SR-4 Devices)
- ☐ Bulletin 4301 (SR-4 Load Cells and Load Beams)
- ☐ Bulletin 4302 (SR-4 weighing of tanks, bins, hoppers)
- ☐ Bulletin 4306 (SR-4 Fluid Pressure Cells)

Name_____ Title_____

Company_____

Address_____

City_____ Zone_____ State_____



NEW...the 400 cycle

vernistat*

a.c. Potentiometer

you asked for!

The 400 cycle Vernistat is an a.c. potentiometer-type voltage divider that combines *high* linearity and *low* output impedance. It is essentially a non-dissipative element adaptable to high temperature operation. Size and mounting dimensions are designed to the BuOrd specification for a size 18 synchro.

Here are the details:

- **high linearity,** inherent in the design principle, is *maintained* over the life of the unit.
- **low output impedance** eliminates need for isolation amplifiers in many applications.
- **high output current capability.**
- **low phase shift** – less than 90 seconds, depending on model.
- **can be coupled with synchros,** resolvers and other components – as well as ganged.
- **nonlinear functions can also be generated.**

Class 5 ball bearings, centerless ground shaft, and an aluminum housing machined to close tolerances combine to make the Vernistat a precision instrument. Shaft seals will be supplied where they are required by environmental conditions.

check these specifications:

Linearity Tolerance	±0.05%
Minimum Output Voltage Increment	0.01%
Output Impedance	less than 130 ohms
Input Voltage	130 v max.
Input Impedance	up to 75,000 ohms

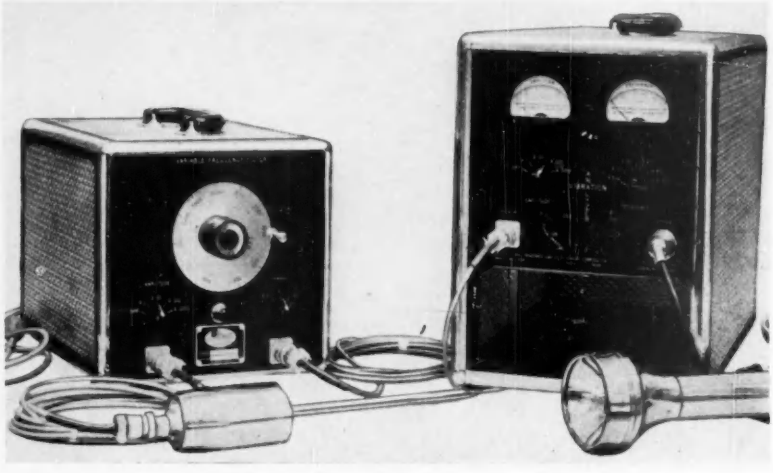
*Trademark

vernistat division

PERKIN-ELMER CORPORATION
Norwalk, Connecticut

NEW PRODUCTS

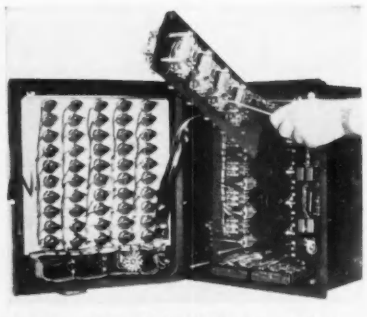
INDICATORS & TESTERS



VIBRATION ANALYZER shows displacement in inches.

Vibration wave analysis is performed by Model 1064 continuously variable filter, above, left, when it is used with the analyzer, right. A tuning range of from 500 to 50,000 cpm or 500,000 cpm covers amplitudes up to 1 in. and down to 0.0001 in. *International Research & Development Corp., P. O. Box 1707, Columbus 16, Ohio.*

Circle No. 9 on reply card



MONITOR CHECKS 25 points for high-low status.

The 25-point scanner above contains 25 sets of red and green lights that show a particular step under control and whether the process as a whole is functioning properly. Each point being surveyed is set by a simple slide-wire adjustment, while points not used are automatically skipped. The scanner checks points at speeds of 1 or 5 per sec. *Fielden Instrument Div. of Robertshaw-Fulton Controls Co., 2920 N. Fourth St., Philadelphia 33, Pa.*

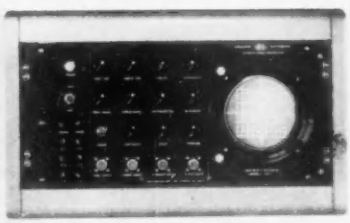
Circle No. 10 on reply card

DIGITAL READOUT: Luminous digital readouts, with from one to six windows, use edge-lit lucite plates. The numbers are ½ in. wide, 1 in. high, and spaced 1⅛ in. apart. *Non-Linear Systems, Inc., Del Mar Airport, Del Mar, Calif.*

Circle No. 11 on reply card

GAS TUBE MONITOR: The Arc-Drop Voltmeter makes arc-drop measurements on gas tubes while they are in operation and predicts end-of-useful-life for thyratrons and phanotrons. *Alectric Mfg. Co., 7842 39th Ave., Kenosha, Wis.*

Circle No. 12 on reply card



SCOPE WITH MEMORY holds waveforms until erased.

This device can be connected to an

From Flight Tests to Figures with Benson-Lehner Data Reduction Equipment. 230 man hours per week are saved by each of Benson-Lehner's six OSCAR Model N data reduction machines at North American Aviation. The machines, used for the digitizing of successive oscillograph channels in the processing of flight test data, have been instrumental in North American's latest achievement... the new world's speed record for operational aircraft set by the North American F-100 Super Sabre. Flight test data from this and other contract planes was formerly reduced by manual reading and calculations. Since the installation of Benson-Lehner machines, North American has been able to save thousands of previous man hours.

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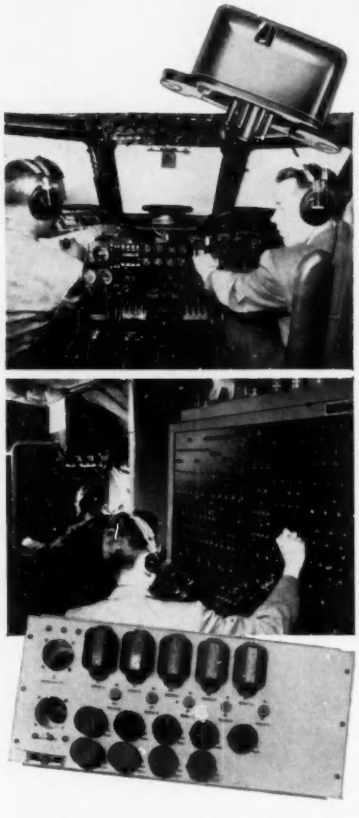
There are over 400 Benson-Lehner installations throughout the world turning out data in widely diversified fields of science and industry.

BARBER COLMAN

ultra-sensitive relays

selected for use on Flight Simulators built by Curtiss-Wright



Reproducing in exact detail all the flight characteristics of the giant C-124 troop and cargo carrier, the Electronic Flight Simulator built by the Electronics Division of Curtiss-Wright permits intensive flight familiarization without personnel ever leaving the ground. In this Simulator's generator system, five Barber-Colman Micropositioners are used. In your applications, too, there is very likely a place for this remarkable ultra-sensitive relay. Various types . . . plug in, solder-lug, screw terminal, hermetically sealed. Operate on input powers of 50 to 1,000 microwatts. Ideal for use as a null detector in resistance bridge circuits, a differential relay in electronic plate circuits, and an amplifier in photoelectric circuits. Can be operated in excess of 100 cps. Write for Bulletin F-3961-4.

Barber-Colman Company

Dept. X, 1448 Rock Street, Rockford, Illinois

NEW PRODUCTS

electrostatically deflected cathode-ray oscilloscope to provide multiple storage of waveforms. The Memo-Scope contains two stable dc amplifiers, which are connected to the associated scope. A separate erase pulse clears the screen. *Advanced Electronics Mfg. Corp., 2025 Pontius Ave., Los Angeles 25, Calif.*

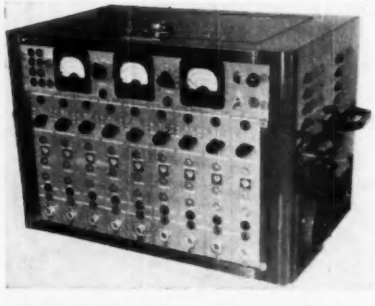
Circle No. 13 on reply card

VTVM: The type 800-B vacuum tube voltmeter features a uhf probe for measuring the level of voltages to 700 megacycles within 1 db. Ranges are as low as 5,000 megohms and 0.001 microamp. *Technology Instrument Corp., 531 Main St., Acton, Mass.*

Circle No. 14 on reply card

LOW FREQUENCY OSCILLATOR: The Type 348 Sine-Wave Generator offers accuracy to within 2 per cent for outputs in the range of ⅛ to 510 kilocycles. Output is 2 watts into 600 ohms. *Allen B. Du Mont Laboratories, Inc., 760 Bloomfield Ave., Clifton, N. J.*

Circle No. 15 on reply card



NINE-CHANNEL DC amplifier for oscillographs.

This machine consists of nine high-gain amplifiers for use with recording oscillographs. Attenuation is accomplished by dividing the output voltage and returning the unwanted gain to the opposite differential amplifier grid. Gain is to 1,100 per channel. Input impedance is 10 megohms. Frequency response is within 1 per cent to 25,000 cps. *United Control Corp., 4540 Union Bay Place, Seattle 5, Wash.*

Circle No. 16 on reply card

WAVE FORM analyzer filters out 24 components.

A complex wave form fed into the above machine can be separated into a maximum of 24 components. Twenty-four cathode-follower amplifiers feed 23 band-pass filters ranging from 30 to 2,000 cps and one 20-cycle low-pass filter. Function is vibration analysis. *Hycor Co., Inc., 11423 Vanowen St., North Hollywood, Calif.*

Circle No. 17 on reply card

LARGE-SCREEN SCOPES: 17- and 21-in. cathode ray indicators, available from Du Mont, couple to the deflection plates of small-screen oscillographs. *Allen B. Du Mont Laboratories, Inc., 760 Bloomfield Ave., Clifton, N. J.*

Circle No. 18 on reply card

MAGNETIC RECORDING HEADS: Four new thimble-sized recording heads for base- or rear-mounting are available from *Shure Brothers, 225 W. Huron St., Chicago 10, Ill.*

Circle No. 19 on reply card

RELAYS, SWITCHES, & TIMERS

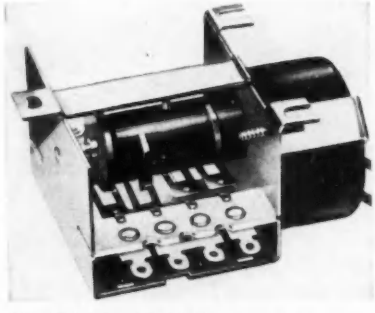
DELAY RELAY is motor-driven for high accuracy.

The above synchronous-motor-driven time-delay relay (new Type 412) features repeat accuracy of within ¼ to 1 per cent. It has 14 ranges, from 6 sec to 24 hrs, in 115, 220, 25, 50, and 60 cycles. Its contacts are rated for 15 amp at 125 vac. Life of over 1 million operations is claimed. *R. W. Cramer Co., Inc., Centerbrook, Conn.*

Circle No. 20 on reply card

MINIATURE ROTARY SWITCH: The Series 7000 switch comes in arrangements ranging from one pole 12 positions to 4 poles three positions, with one, two, or three decks. Positive 30 deg indexing is standard. It mounts on a ¼-in. diam shaft. Contacts will break a 250-ma circuit at 50 vdc. OD is 1.16 in., torque 1½ in.-lb. *International Instruments Inc., New Haven, Conn.*

Circle No. 21 on reply card



INTERVAL TIMER sequences four operations.

The little timer shown here controls four different circuits to generate four different operations during an 8-sec cycle. Use in small automatic devices requiring a sequence of opera-

BARBER COLMAN

Small Motors

chosen to power water circulation system in Lipman "Ice Boy" ice tip machine

With a Lipman "Ice Boy" ice tips can be automatically made and stored at the rate of 1,000 to 1,600 per day in various accurately controlled sizes up to 1¾" diameter, 2¾" length.

Only moving part of this machine produced by Lipman Refrigeration Division of Yates-American, Beloit, Wisconsin, is a revolving paddle which circulates water and moves tips to the storage compartment. This is powered with a Barber-Colman PYAZ geared motor with these "plus" features: rugged, precision gear train . . . porous bronze bearings . . . large oil wicks . . . high starting torque.

If you have a project involving small motors, let Barber-Colman engineers help you get the exact motor for the job.

FREE DATA SHEETS ON WIDE LINE OF SMALL MOTORS

The Barber-Colman line includes unidirectional, synchronous, and reversible motors — up to 1/20 hp. With and without reduction gearing — open or enclosed types. Expert engineering service available. Write today, tell us your problems, ask for free data sheets.

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DEPT. X, 1248 ROCK STREET, ROCKFORD, ILLINOIS

Small Motors • Automatic Controls • Industrial Instruments • Aircraft Controls • Air Distribution Products
Overdoors and Operators • Molded Products • Metal Cutting Tools • Machine Tools • Textile Machinery

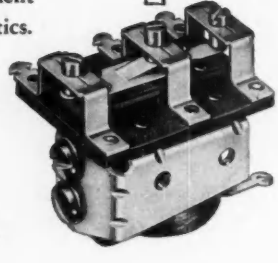
UNIQUE SENSITIVE RELAY

incredibly small, lightweight and adjustable!

ADVANCE "SO" SERIES

Here for the first time is a sensitive relay only 1-7/32"x 1-1/8"x 1-1/4"... weighing only 1-1/2 ounces, and adjustable over a wide range. You get much more latitude with this relay in designing for tiny areas.

The Advance "SO" is set at the factory to operate on 10 milliwatts. User can adjust it down to 2 milliwatts, or any desired pick-up or drop-out, by means of fine screw contacts. A balanced armature provides extremely sensitive operation. The unit is highly efficient, ruggedly built, and offers excellent shock and vibration-resistant characteristics.



Contact arrangement is SPDT. Coil resistances: 4000, 6500 and 10,000 ohms. Life expectancy: 250,000 operations. Available in open types... dust-tight or hermetically sealed enclosures. Now in quantity production. Advance "SO" relays are priced amazingly low. Write for literature.

Coil Resistance	Pick Up Voltage	Pick Up Current	Drop Out Voltage	Drop Out Current	Max. Coil Voltage for Continuous Duty	Overtravel	Contact Gap
4000	6.4 V	1.6 MA	3.2 V	.8 MA	110 V	.0015	.002/.003
6500	8.1 V	1.25 MA	3.9 V	.6 MA	140 V	.0015	.002/.003
10,000	10 V	1 MA	5 V	.5 MA	175 V	.0015	.002/.003

ADVANCE ELECTRIC AND RELAY CO.

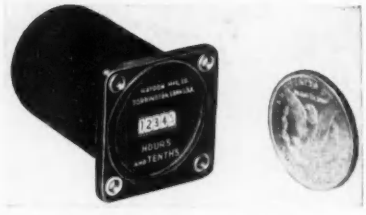
ADVANCE RELAYS

2435 N. NAOMI STREET, BURBANK, CALIF.

AN ELGIN NATIONAL WATCH COMPANY AFFILIATE

tions, such as some vending machines or machine tools, is envisioned. A variety of cycle lengths and poles are supplied. *P. R. Mallory & Co., Inc., Indianapolis, Ind.*

Circle No. 22 on reply card



TINY TIMER for aircraft features hermetic sealing.

Special feature of this elapsed time meter is the 1½ in. diam case. Two models, one indicating in $\frac{1}{10}$ hr steps to 9,999.9, and the other in $\frac{1}{10}$ min to 9,999.9 min, are available. Hermetically sealed, the little timers operate on 400 cycle current and mount on either side of panels. *Haydon Mfg. Co., 245 East Elm St., Torrington, Conn.*

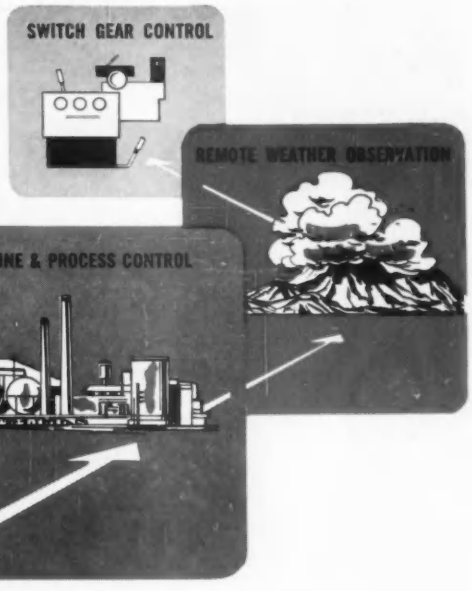
Circle No. 23 on reply card

1-MICROAMP signals handle temperature controller.

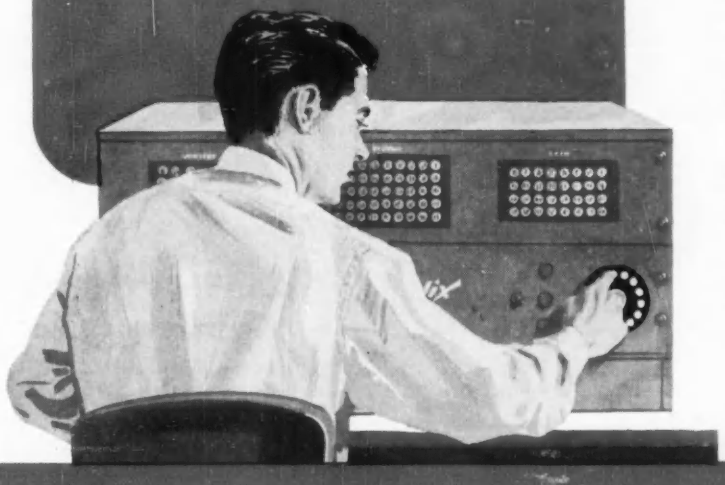
The little contact on-off controller above consists of a pyrometer indicator circuit and load relay that will handle up to 5 amps at 115 vac. Temperatures as high as 2,500 deg F can be controlled to within 1 per cent of scale. Control current variations of 1 microamp are said to operate the regulator. Name is Model PB. *Automation Instrument Corp., 1516 Summer St., Philadelphia 2, Pa.*

Circle No. 24 on reply card

NEW STANDARDS OF ACCURACY AND DEPENDABILITY IN INDUSTRIAL REMOTE CONTROL AND TELEMETERING WITH...



Bendix-Pacific ELECTRO-SPAN SYSTEMS



Bendix-Pacific Electro-Span data transmission systems remotely measure liquid level, flow, pressure, temperature or shaft position, and remotely control pumps, valves, motors and similar equipment with accuracy and dependability never before attainable at such low costs.

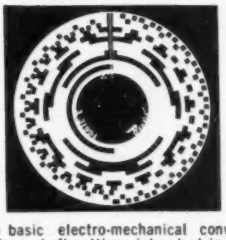
These are true digital systems, assuring consistent performance and freedom from error, over any distance. The systems can be operated over all types of communication channels.

Under the Bendix-Pacific unitized construction, these systems are comprised of standard assemblies offering maximum flexibility with low cost.

Bendix-Pacific engineers will gladly propose a system to meet your specific requirements.

TYPICAL INPUT/OUTPUT COMPONENTS

Digital Coders

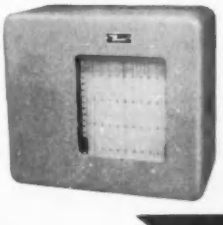


These basic electro-mechanical converters transform shaft settings into electrical code signals for long distance data transmission. They are attached to standard measuring instruments, such as flow meters and tachometers, and to control shafts.

Digital Pressure Gauges

A standard Bourdon tube pressure gauge which serves as a local pressure indicator and as a digital converter for use in transmitting pressure data electrically over long distances.

Digi-Graphic Recorders



A simple digital-to-graphic converter which directly transcribes received digital measurement data into a permanent graphic record.

Visual Indicators

including digital synchro indicator and decimal lamp register.

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Bendix Aviation Corporation
NORTH HOLLYWOOD, CALIF

now . . . new technical data bulletin on delay lines from

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New Technical Advances, New Materials and Techniques Have Resulted in Delay Lines of Unusual Characteristics . . . And At Low Cost:

If you use delay lines in: Telemetering — Digital or Analog Computers — Pulse Circuits — Coders and Decoders — Navigation Systems — Stable Time Reference Units — or in special applications — you'll find this brand new technical bulletin of great interest and use in your work.

CHARACTERISTICS OF NEW STANDARD* UNITS

All Standard units are *guaranteed* to have the following characteristics:

Temperature coefficient of delay less than 50 parts per million per °C.
Operating temperature range: —55C to 125C.
Delay tolerance 3%.
Spurious signals less than 5%.
Characteristic impedance tolerance 5%.
Attenuation in DB approximately 0.1 to 0.2 *times delay-to-rise-time ratio.*

*Custom units are built to even more stringent specifications.

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New Standard Series
Precision Audio Delay Lines
Custom Designed Units
Special Applications
Design Formulae
Typical Circuits
Characteristic Impedance
Attenuation
Delay Time
Rise Time
Delay-To-Rise-Time Ratio
Bandwidth
Phase Linearity
Spurious Signals
Operating Temperature Range

EPSCO INCORPORATED

SEND FOR BULLETIN DL-55 TODAY! 588 Commonwealth Ave., Boston, Mass.

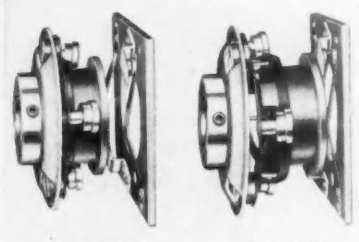
NEW PRODUCTS

SAMPLING SWITCH: A new sampling switch is available with 1, 2, or 3 concentric poles, 60 contacts per pole, a built-on dc or ac motor, and gear reduction assembly. The maker offers a variety of contact arrangements with individually adjustable phasing among poles. *General Devices, Inc., P. O. Box 253, Princeton, N. J.*

Circle No. 25 on reply card

SEALED PLUG-IN RELAY: A new 3½-in.-high plug-in sealed relay features contact closure in 10 millisec. Contacts are rated for 1.5 amp inductive and coil operating power of 250 milliwatts. *Hedin Tele-Technical Corp., 87 Dorsa Ave., Livingston, N. J.*

Circle No. 26 on reply card



UNDERSPEED SWITCH acts as torque limiter.

The maker says that operational tests of this switch show a life of up to 3 million cycles. It opens circuits when a rotating element runs underspeed, a condition that can be laid to loads large enough to damage some aspect of the torque source. Consequently, this "torque limiter" prevents machines from damaging themselves due to a jammed condition. *Torq Engineering Products, Inc., Interstate St., Bedford, Ohio.*

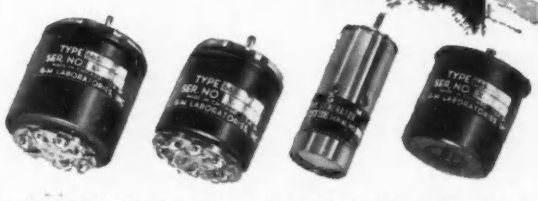
Circle No. 27 on reply card

CYCLE TIMER: A new repeat cycle timer has an electronic timing circuit with two cold-cathode triodes. On and off cycles are independently adjustable from 0.1 to 12 sec. The only moving part is an SPDT relay with 5 amp contacts. *G. C. Wilson & Co., 1915 Eighth Ave., Huntington, W. Va.*

Circle No. 28 on reply card

Don't make your servo system a SLAVE to its motor!

Let G-M supply the *right* motor to fit your system! By specializing in servo motors—not systems—G-M can offer you a broader range of sizes and characteristics. You choose from *all* the standard sizes . . . plus standard sizes specially modified to meet specific circuit requirements. Or, request a G-M tailor-made servo motor with the correct combination of impedance, voltage and other values to meet your exact circuit requirements. You get the right motor—*right on time*—when you specify G-M Servo Motors!



• SERVO MOTORS • MOTOR GENERATORS • SYNCHRONOUS-HYSTERESIS MOTORS

Write for literature and information! Use G-M charts and specifications to select the best values for the control phase of your servo motor. Whether you are designing a new system, or seeking better performance in an existing system, let G-M help.

GM

G-M Servo Motors

manufactured by the Components Division of

G-M LABORATORIES INC.

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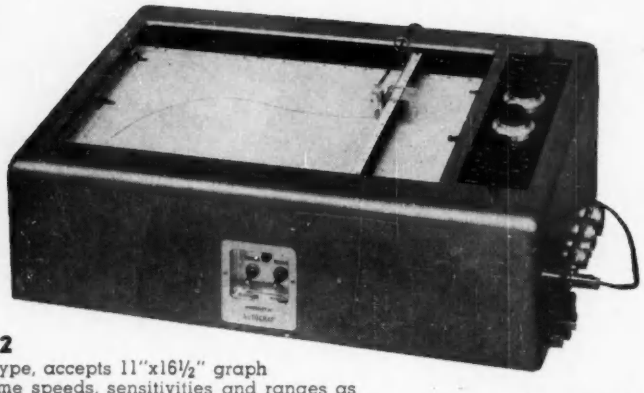
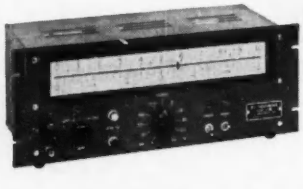
THE MOSELEY
AUTOGRAF
trade mark
X-Y RECORDER

MODEL 1. drum type, accepts 8½"x11" graph paper; traverses each axis in 1 second; has full scale ranges of 5 millivolts to 100 volts; zero set anywhere on the paper; portable, self-contained; available also as a curve follower for electrical read-out of drawn curves.

AUTOGRAF Recorders, MODELS 1 and 2, provide all the features needed for graphic recording of test data, point plotting, and curve following for readout purposes.



MODEL 2
Flat bed type, accepts 11"x16½" graph paper; same speeds, sensitivities and ranges as MODEL 1; zero set anywhere on paper plus one full scale length of zero-offset; inputs provided for analog recording, point plotting from digital sources, and curve following for computer or data reduction use.



MODEL 20 DC VOLTMETER is a servo-actuated, fast, accurate and sensitive instrument. Has large, easy-to-read scale for general laboratory use where ranges from 3 millivolts to 300 volts are desired. For data handling it is furnished with a built-in Coleman digitizer and delivers digital output for operation of printers, typewriters, tape or card punches, etc.

MODEL 30 CARD TRANSLATOR converts information from punched cards into point form for automatic plotting. Handles up to 50 cards per minute, 10 to 200 counts per inch. Plugs directly into MODEL 2 recorder, controls both card reader and recorder for completely automatic operation.

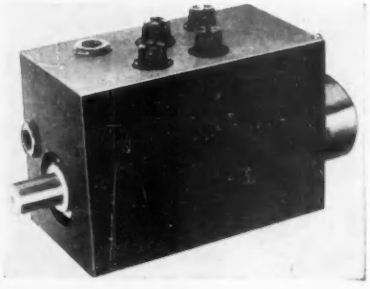
MODEL 40 KEYBOARD provides a convenient means for plotting large amounts of tabular data in point-curve form. Self-contained voltage source together with full three column keyboard in both X and Y axes; unit plugs directly into MODEL 2 AUTOGRAF.

Bulletins describing these instruments are available and we'll be glad to send them to you. Write . . .

F. L. MOSELEY CO., 409 North Fair Oaks Avenue, Pasadena 3, California

NEW PRODUCTS

CONTROL VALVES



POSITIONAL SERVO VALVE for mechanical feedback.

The Model CO-5 Servo Control Valve is designed for follow-up positioning systems in which mechanical input signals are obtained from cams or linkages. Sources of positional feedback can be differential input linkages or valve body displacement. *Hydraulic Controls Co., 87 Terrace St., Roxbury 20, Mass.*

Circle No. **29** on reply card

BELLOWS-SEALED valve is diaphragm-controlled.

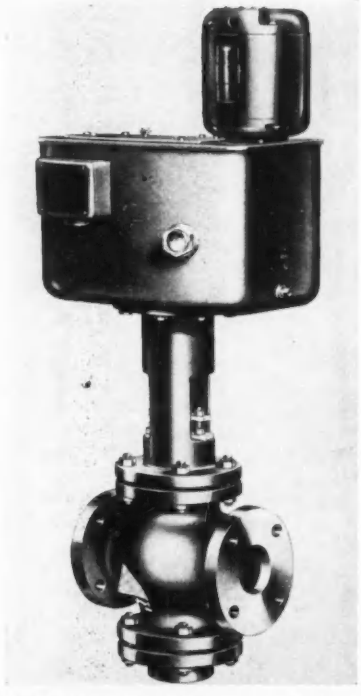
The small valve shown above has Teflon seating and packing. Bellows are rated at 500 psig from minus 70

deg to 700 deg F. Port is ½ in. George W. *Dahl Co., Inc., Bristol, R. I.*

Circle No. 30 on reply card

SERVO VALVE: Moog's dry solenoid servo valve is in production. Model 2000 will furnish any maximum output flow from 1,000 to 3,000 psi. A torque motor isolated from the fluid produces full valve output with a differential current of plus or minus 0.8 ma. Natural frequencies of 65 cps can be achieved when the unit is used in servo loops. It uses 0.1 gal of fluid per min. to drive the internal servo that positions the four-way main valve. *Moog Valve Co., Inc., East Aurora, N. Y.*

Circle No. 31 on reply card



POWERFUL VALVE responds to delicate signal.

Control signals of less than 50 milliwatts cause this valve to move at a speed of more than 1 in. per sec with a thrust of 600 lb or more. Working through its own hydraulic power, the valve feeds electric signals into amplifiers having proportional band, rate, and reset functions. It operates this way: the incoming signal is fed through a coil suspended in a magnetic field. This coil moves in the field a distance proportional to input cur-

HOKUM ON PREAMPLIFICATION

Way out in our back room we have a section devoted to Engineering.[1] One purpose of this group is to see to it that our relays work in the job for which our customers purchased them. Our man Waldo Hokum, one of the members of this group, has for years been untangling circuit problems[2] that have had an unflattering effect on our relays and during this time he has been able to segregate many problems and assemble them in definite categories.[3]

One category soon became so large[4] that we had to take more floor space to make room for it — that was, and is, how to get conventional relay response to low impedance D.C. signals of the order of 0.1 to 100 microwatts. Many relay uses call for amplifying these signals so that they will be strong enough to activate even our most sensitive relays.[5] This is especially important to people who work with photocells, thermocouples and the like.

Waldo stuck with this one through various stages of vacuum tubes, transistors, toroidal coil magnetic amplifiers and such, but never was really happy about his progress.[6] There was always something like high cost, fragility or instability to cast a dark shadow on his otherwise blissful existence.[7] It wasn't until he designed and made his own magnetic amplifier that he began to see the sunshine again.[8]

What he came up with was a magnetic amplifier which, among other things, included conventional bobbin wound coils rather than toroids. This made our directors happy,[9] because even they know that the manufacturing costs are *much* less with bobbins, and, what is more important, it made Waldo happy.[10] He discovered that his new gismo,[11] together with the circuitry that he developed to go with it, had some rather interesting specs,[12] generally as follows:

MAGNETIC AMPLIFIER RELAY
SERIES 8000*

Sensitivity:	0.1 to 100 microwatts	
Nature of signal:	D. C. from 0.1 to 30,000 ohms[13]	
Relay response:	Polarity sensitive — snap action	
Contact form:	(1) 3-position, center neutral (2) SPDT	
Contact rating:	1-5 amperes at 28VDC or 115VAC	
Speed of response:	30 to 300 milliseconds depending on overdrive and L/R of input circuit	
Environment:	Standard	Available
Vibration	5 g. to 30 cps.	10 g. to 500 cps.
Temperature	0° to 50°C	−55° to 125°C
Shock	10 g	100 g
Power Supply:	115V @ 60 cps.	115V @ 400 cps.

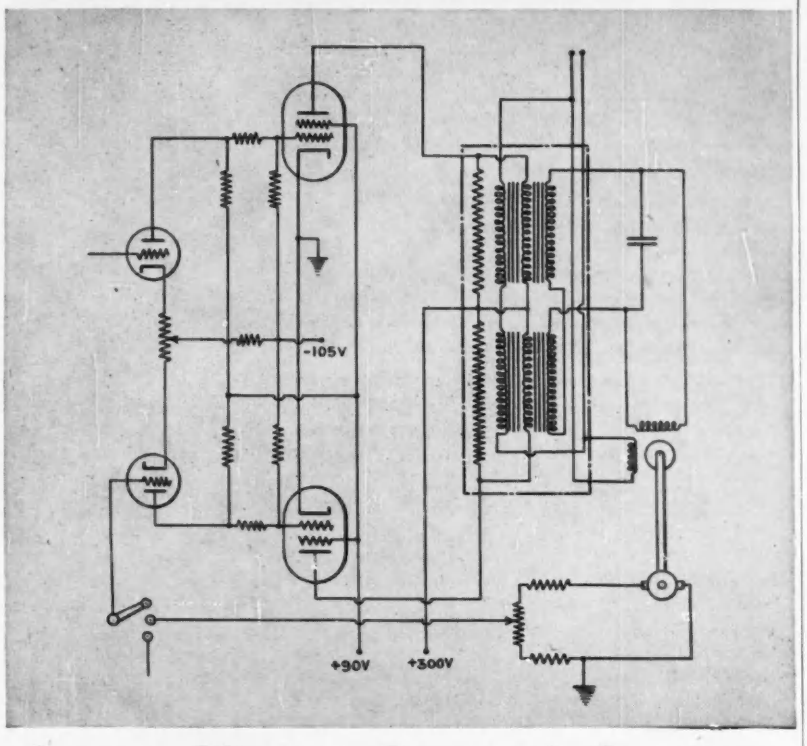
This thing is now at the point where it would be worth your time to play around with — that is if the above specs bracket your problem generally and especially if you need to monitor the conditions of bridge balance[14] or compare the outputs of low impedance D.C. signal sources.

If such is the case, Waldo has some sample "packages" that not only include his magnetic amplifier, and a Sigma Relay (natch), but also the circuitry that makes the thing work.[15] If you think you'd like one of these to fool with, or wish more information on this subject, we suggest you write to us, attention of our man Waldo. His name really is spelled Holcombe.

SIGMA

SIGMA INSTRUMENTS, INC.
69 Pearl St., So. Braintree, Boston 85, Mass.

SINCE 1915 LEADERS IN AUTOMATIC CONTROL



Servo Motor Control System

Most engineering ingenuity concentrates not on basic principles, which are relatively simple, but on the fine details that make the difference between good and poor design, between high and low cost, or between efficient and inefficient component arrangement. For instance, the motor control system patented by the Ford Instrument Company. The purpose of the system is to provide a sensitive control system to make an induction motor respond accurately to a relatively small reversible input signal. This system employs saturable-core transformers to combine the sensitivity of vacuum tube amplifiers with the high power-carrying capacity of saturated-core devices. This also facilitates the problem of matching the motor impedance with that of the amplifier.

In the circuit shown the first pair of tubes act as a phase inverter, with the control signal applied to the grid of one inverter tube. The feedback signal, produced by a d-c generator coupled to the controlled motor, is applied to the inverter tube. The output of the inverter is the signal of the servo loop. The second pair of tubes acts as a driver-stage for the saturated transformers that supply one winding of the controlled two-phase induction motor; the other motor winding is connected to the power line.

This is typical of the things Ford engineers do . . . every day. If you have a control problem it will pay you to talk to the Ford Instrument engineers.

83

FORD INSTRUMENT COMPANY
DIVISION OF SPERRY RAND CORPORATION
31-10 Thomson Avenue, Long Island City 1, N. Y.

ENGINEERS
of unusual abilities can find a future at FORD INSTRUMENT COMPANY. Write for information.

NEW PRODUCTS

rent. In doing so, it positions a jet nozzle that operates the control valve. *Askania Regulator Co., 240 E. Ontario St., Chicago 11, Ill.*

Circle No. 32 on reply card

TINY pressure regulator has fast response.

The little machine above is a back-pressure controller. Called the Micro Delta P, it's said to have microsecond control without hunting and to provide square wave pressure response. *Industrial Engineering Corp, 525 E. Woodbine, Louisville, Ken.*

Circle No. 33 on reply card

POWERED VALVES: Ledeen Model PON, a standard 4-way disc valve for air, gas, oil, or water service, is operated by a three position air- or gas-powered actuator. *Ledeen Mfg. Co., 1600 S. San Pedro St. Los Angeles 15, Calif.*

Circle No. 34 on reply card

PULSE PRODUCTS

CONVERTS punched card data for analog plotters.

The machine shown above converts decimal notation on punched cards into an analog voltage for X-Y plotters. The converter uses relays and resistors to alter the output of the

Librascope Model 227 Decimal Keyboard or the IBM 519 Reproducer or 523 Punch. Plotted curves are said to be accurate within 0.25 per cent. The device will handle 60 cards per min. Individual cards can be read on the panel. *Librascope, Inc., 808 Western Ave., Glendale, Calif.*

Circle No. 35 on reply card

SINE AND PIP GENERATOR: As its shaft rotates, a small Dalmotor generator produces a two-phase sine valve and two indicating pips per revolution. The pips are produced by 10 deg switches set 180 deg apart. One model is for 1,200 rpm operation (producing 20 cps) and another for 2,100 rpm (35 cps). *Dalmotor Co., 1381 Clay St., Santa Clara, Calif.*

Circle No. 36 on reply card

DIGITAL MULTIMETER aids accurate readings.

The 503 Digital Multitester displays its ohm and volt readings to three figures. Electronic decade counters give the instrument an accuracy in the dc range of 0.15 per cent of full scale, through the ranges of 0.01 to 1,000 v. The ac volt readings are within 1 per cent full scale, and the ohms (10 to 10 megohms) within 0.2 per cent. *Laboratory for Electronics, Inc., 75 Pitts St., Boston 14, Mass.*

Circle No. 37 on reply card

DELAY LINE: The Model F-135 Delay Line provides a delay of 74 microsec plus or minus 1 per cent in a can the size of a soap-cake. It's divided into eight sections and has a nominal impedance of 1,170 ohms. Attenuation within the frequency

From MOOG . . .

a Dry Solenoid Servo Valve

For those electro-hydraulic servo systems which require valves of high dynamic performance, reliability, small size and low weight, Moog units have achieved recognition as the industry standard.

And now, for those systems in which the fluid contains entrained iron, Moog has developed the Model 2000 Servo Valve. These units feature a dry solenoid which eliminates the possibility of torque motor contamination due to magnetic particles. These valves comply with requirements of MIL-H-5440A and are smaller and lighter than other Moog units of the same flow capacity.

Moog Valves, including Model 2000, are proportional type, electrically actuated, hydraulic, four-way valves featuring high dynamic response, sensitivity, linearity, and reliability. Production models are designed to operate in hydraulic systems of from 1000 to 3000 psi pressure. Rated output flows from 0.1 to 50.0 GPM for control currents of from 2.0 to 40.0 milliamperes as specified are available in production units.

Conventionally the valve input is from a balanced push-pull DC amplifier and the valve flow output is applied to a piston or hydraulic motor. An electric signal proportional to piston position or motor angular rotation is fed back to the amplifier to give a closed servo loop.

Typical applications for these units are in servo systems used for guided missile and aircraft flight controls, radar scanner actuation, contour following machine tools, and automatic packaging equipment.

For details write for Bulletin 2000-2

MOOG VALVE CO., INC. PRONER AIRPORT EAST AURORA, N. Y.

CROSS OFF

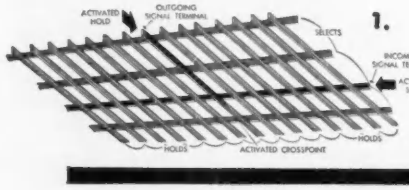
COMPLEX CONTROL PROBLEMS with

KELLOGG CROSSBAR SWITCHES

First used and overwhelmingly approved in the telephone industry, the KELLOGG Crossbar is one of the most versatile switch devices yet developed for industrial use. Simple in its operation — durable and dependable — it solves hundreds of multiple or complex switching problems at small cost.

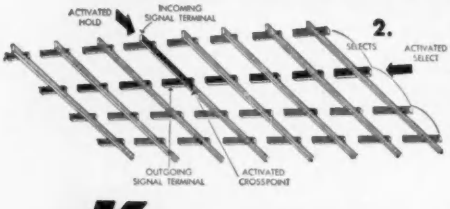
It does away with the limitations inherent in relay trees. It provides connections as low as 25 to 30 milli-seconds for one or many input circuits to one or many output circuits. With Crossbar several switching operations may be done at the same time—any circuit may be held while other circuits are switched. Because Crossbar switch points move only a few thousandths of an inch, wear and maintenance are practically eliminated. Contacts are of paladium metal; gold can be provided.

The entire switch may be drawer mounted for easy inspection without disrupting service. The only wiring normally needed is to connect the input and output circuits. Shown below are the various types of electrical connections possible with KELLOGG Crossbar.



1.

Drawing No. 1 illustrates the basic Crossbar principle which permits any of several incoming circuits to be connected to any of several output circuits. This type of switch can connect any of 60 circuits, 3 at a time, to any of 75.



2.

Drawing No. 2 shows a means of switching one incoming circuit to many possible outgoing circuits—accomplished by removing every other vertical. Thus, instead of having one cable terminal at one end of the switch, each remaining vertical has its own cable connection. This type of switch can easily be adapted to switch one circuit to any of 936.

KELLOGG DIVISION OF IT&T

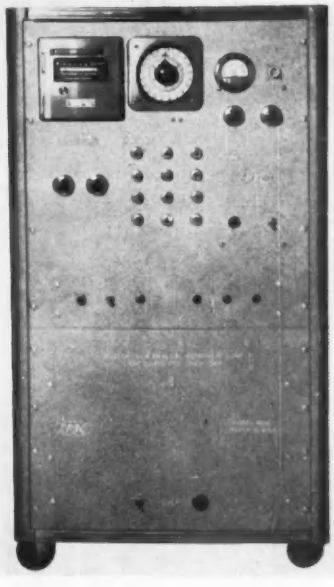
Write For This Free, Fact-Filled Booklet Today Dept. 72-J

KELLOGG SWITCHBOARD AND SUPPLY COMPANY
A Division of International Telephone and Telegraph Corporation
SALES OFFICES: 79 West Monroe Street, Chicago 3, Illinois

NEW PRODUCTS

range of 300 to 15,000 cps is less than 0.2 db. *Control Electronics Co. Inc., 1925 New York Ave., Huntington Station, N. Y.*

Circle No. **38** on reply card



SQUARE WAVE pulser has microsec rise time.

The Model 300, shown above, produces square pulses with a millimicrosecond rise time and widths varying from 0.001 to 0.1 microsec. There are three pulse outputs with independent amplitude adjustment through an 0.006 to 100 range in 1 db steps. Output impedances of from 50 to 200 ohms are accommodated. *Electrical & Physical Instrument Corp., 42-19 27th St., Long Island City 1, N. Y.*

Circle No. **39** on reply card

TIME RECORDER totals, shows machine, process cycles.

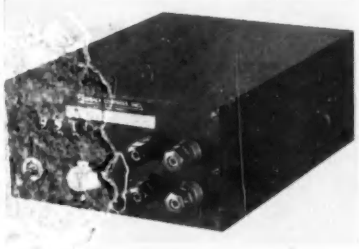
Using electric current sensitive paper, the Time Totalizer feeds its time-marked recording paper, sensitive to electric current, at rates of 1 in. per 5, 15, or 60 min. A counter indicates total "on" time. The recorder is used for on-off controller monitoring, production cycle recording, etc. *Standard Instrument Corp., Div. of Heat-Timer Corp., New York 12, N. Y.*

Circle No. **40** on reply card

PULSE RATE flow sensor uses 0.00003 gal scale.

A unique, ⅛-in. flow sensor converts fluid rate into electrical pulse rate through the range of 0.07 to 0.7 gal per min. Each pulse represents 0.00003 gal. A signal frequency of 60 cps is produced at approximately 0.15 gpm. Operating temperature range is minus 300 to plus 450 deg F. It fits a standard ½-in. male flared tube connector for inlet and outlet. This device can convert flow rate into digital notation directly through the use of an electronic counter or into an analog voltage by the proper RC circuit. *Potter Aeronautical Co., Route #22, Union, N. J.*

Circle No. 41 on reply card



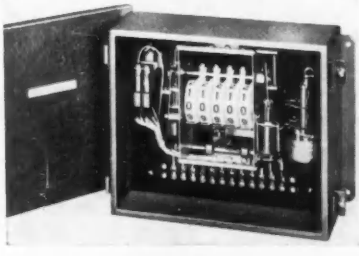
DIGITAL VOLTMETER features high accuracy.

The Digi Volt is a compact digital voltmeter available with three- or four-digit readout and automatic polarity detection. *Feedback Controls Inc., 1332 North Henry St., Alexandria, Va.*

Characteristics

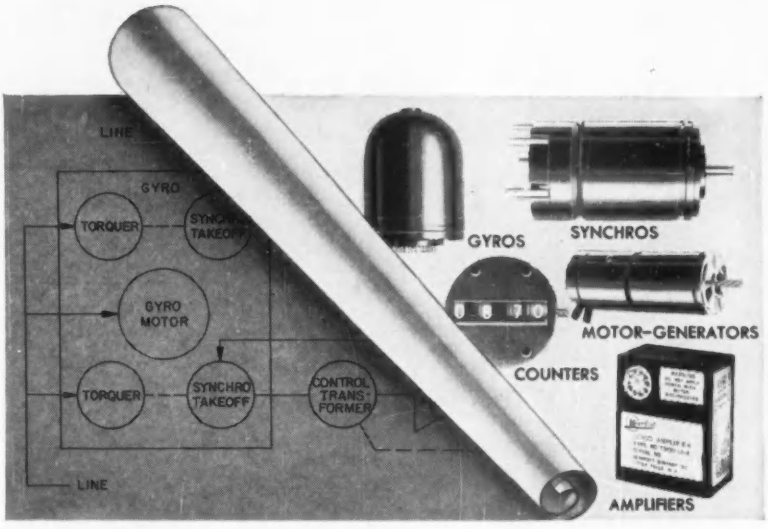
Accuracy .....within 0.5 per cent
Speed .....15,000 counts per min.
Input impedance .....500 K min
Reference voltage ....plus or minus 100 vdc at 2 ma

Circle No. 42 on reply card



BATCH COUNTER closes circuit on preset figure, recycles.

The above counter is designed to



KEARFOTT

. . . from problem through production

Engineering ability and production facilities are as important to you as the characteristics of the components you select. After components are approved, you are dependent upon your supplier . . . dependent upon him for engineering assistance . . . dependent upon his ability to produce quality products in the required quantities.

Many of the servo motors, synchros, gyros and systems in use today had their inception on the drafting boards of Kearfott's engineers. This is proof of Kearfott's engineering ability. Kearfott offers complete engineering service before, during and after the purchase of a component.

Modern buildings, over 430,000 square feet of floor space, equipped with the latest in precision machinery, manned by 3,400 highly skilled specialists, are your assurance of Kearfott's ability to produce.

Yes, Kearfott is a dependable source of supply. If you have a design problem or require a special or standard component, contact Kearfott.

KEARFOTT COMPONENTS INCLUDE:

Gyros, Servo Motors, Synchros, Servo and Magnetic Amplifiers, Tachometer Generators, Hermetic Rotary Seals, Aircraft Navigational Systems, and other high accuracy mechanical, electrical and electronic components.

Send for bulletin giving data of components of interest to you.

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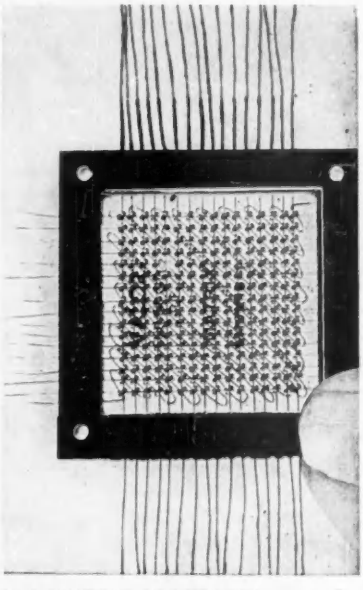
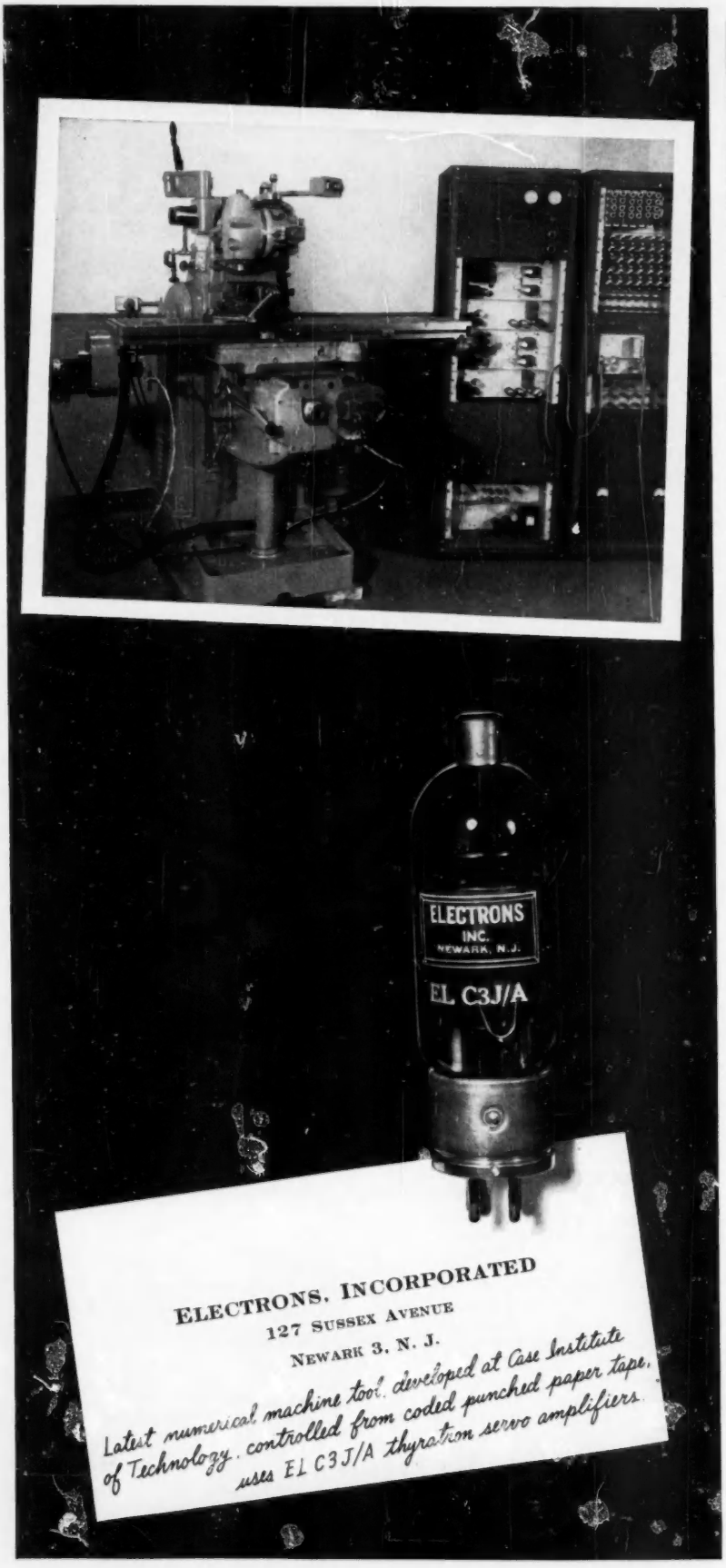
measure batches of items on a production line, through a machine, etc. It subtracts one from a preset figure with the receipt of every pulse. When zero is reached, a control or alarm circuit is closed and the counter automatically adds pulses up to the preset figure. At this point the control circuit closes once more. This cycle continues without attention. *Spencer Mfg. Co., 3253 N. Cicero Ave., Chicago 41, Ill.*

Circle No. 43 on reply card



MAGNETIC MATRICES speed digital computer mock-ups.

Mock-ups of digital computer memories are facilitated by small-scale models built from kits consisting of matrices similar to the one in the cut. These kits also contain switches, driver transformers, work-select matrix switches, and impedance matching transformers. The 256-digit square matrix comes with a single diagonal readout line using the half-current principle, or one diagonal line and another that passes through all the cores in the same polarity as the X and Y lines. Also available is a 256 four-digit word storage array with each word line brought out separately so that only the desired cores are disturbed on read-in and out. Two readout leads are passed through each of the cores of the digit array, one in the same polarity through all of the cores and another that alternates.


ELECTRONS
INC.
NEWARK, N.J.
EL C3J/A
ELECTRONS, INCORPORATED
127 SUSSEX AVENUE
NEWARK 3, N. J.
Latest numerical machine tool developed at Case Institute of Technology, controlled from coded punched paper tape, uses EL C3J/A thyratron servo amplifiers.

Included among available components are current transformers for connecting driver tubes to the individual branch lines of the matrices, or to matrix switching units. The latter are also available. *Valor Electronic Components Co., 5808 Marilyn Ave., Culver City, Calif.*

Circle No. 44 on reply card

SOME DETECTORS

SENSITIVE motion transducer senses moving metal.

The little instrument above is a new, high-sensitivity model of a well-established motion transducer. Its output voltage is produced when the magnetic field of a built-in permanent magnet is distorted. This distortion may be created by the passing teeth of a gear, or by the projection or eccentricity of a rotating shaft. The stainless steel body is about the size of the mike cable connector it resembles. Impedance is 2,800 ohms at 1,000 cps. It's called the Model 3030. *Electro Products Laboratories, 4505 N. Ravenswood Ave., Chicago 40, Ill.*

Circle No. 45 on reply card

MOTION TRANSDUCER: The information we have tells us Model 50 A is extremely similar to the one above. *Minatron Corp., Belle Mead, N. J.*

Circle No. 46 on reply card

PRESSURE PICKUPS: Model S-6 pressure transducer is a single coil diaphragm-type variable inductance unit, $\frac{7}{8}$ in. diam by $\frac{7}{8}$ in. long. Its rise

Let's talk price on

GLASS-TO-STEEL HERMETIC TERMINALS

Since the day Fusite started business we've planned, worked and talked quality. The price of Fusite Terminals has always been set by what it cost to produce them plus a reasonable profit.

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Our greatly increased volume of business, has so cut our costs that we are able to make satisfactory profits on reduced prices with quality hitting new highs.

If yours is one of those companies which have felt Fusite quality was a luxury you could not afford—that our terminals were better than you had to have, we'll be happy to quote today. You'll be happy, too.

Write Department N-3

THE FUSITE CORPORATION
6026 FERNVIEW AVENUE
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Design for Low Control Cost...

ARENS "Seven Standards" may help you save money.

ARENS PUSH-PULL CONTROLS

Low in price, easy to install, there are seven standard Arens designs to meet light, medium and heavy load requirements. They are available with a variety of control heads, casings, and end fittings. Special controls can also be designed to meet specific requirements. Design with Arens Controls in mind . . . and save.

Write for Catalog

ARENS CONTROLS, INC.

2027 Greenleaf Street, Evanston, Illinois

NEW PRODUCTS

time to a step input is about 50 microsec. Pressure overloads by a factor of 10 do no harm to it. Standard pressure ranges are from 1 to 500 psi. *Ultradyne Engineering Labs, Inc., P. O. Box 8007, Albuquerque, N. M.*

Circle No. 47 on reply card

LOW-LEVEL magnetic amplifier for sensor inputs.

The type Se-LL-60, designed for use with dc inputs from thermocouples, photocells, strain gages, current shunts, and similar sources, features a power gain of many thousands. Its dc output can operate a 45 milliwatt relay with an input signal of only 0.2 microwatts. In a typical performance, 150 microamp input produces 55 milliwatts. Cost in quantities is near $50. *Stator Electric Corp., 46-25 58th St., Woodside 77, N. Y.*

Characteristics

Control coil resistance	10 to 1,000 ohms
Power source	25 v 60 cps
Time constant	1 to 10 cycles, varying with signal source impedance
Size	2 in. by 2½ in.

Circle No. 48 on reply card

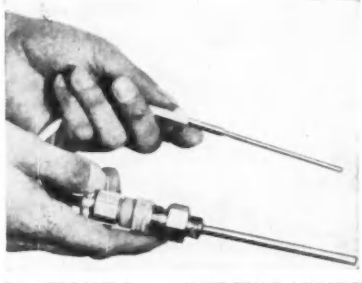
HIGH SPEED RADIATION DETECTOR: Half-second readings of 98 per cent of any temperature change is claimed for a new group of radiation pyrometers. Wide or narrow angle models for intermediate or high temperature ranges are in stock. *Minneapolis-Honeywell Regulator Co., Industrial Div., Philadelphia 44, Pa.*

Circle No. 49 on reply card

GEIGER COUNTER for x-ray spectrography.

This Geiger counter tube is designed for X-ray spectrographic work involving elements such as phosphorous, silicon, and aluminum. It has a resolving time of approximately 150 microsec, a threshold of approximately 800 v, and a background, with 2 in. of lead shielding, of 75 counts per min max. *North American Philips Co., Inc., 750 S. Fulton Ave., Mount Vernon, N. Y.*

Circle No. 50 on reply card



PLATINUM TEMPERATURE SENSOR: A platinum temperature sensing element gives a new resistance temperature detector high-speed response through the range of 330 to 1,380 deg F and an accuracy to within plus or minus 0.6 per cent. *Fielden Instrument Div. of Robertshaw-Fulton Controls Co., 2920 N. Fourth St., Philadelphia 33, Pa.*

Circle No. 51 on reply card

FEEDBACK FANCY

Needed: Some way to unsnarfle poor old Dobbin after chow.

Suggested: Why not a level indicator that sounds a gong when the feedbag is nearly empty?

BOWMAR

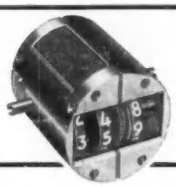
INSTRUMENT . . .

. . GEARED FOR DESIGN, PRODUCTION AND SERVICE IN

PRECISION ELECTROMECHANICAL COMPONENTS

1002 Precision Miniature Speed Reducer, available in standard ratios from 13:1 to 4000:1.

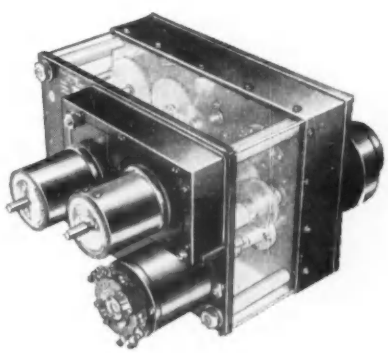
107U Universal Gear Train Kit, features 20 common ratios to satisfy most laboratory needs.



1502 Angle Counter, indicates angular increments from 0° to 375° with return to 0°. Reversible operation.

1384-GH Servo Motor Gear Head, meets MIL-E-5272-A requirements. Adapts to MK 4 or equivalent motors.

Design and production of custom electromechanical assemblies are Bowmar's prime functions. Due to wide customer acceptance, many such assemblies—and modifications of them—have been standardized and catalogued for quantity production. Data on the representative group illustrated above and on parallel services and products will be sent on request. There is a Bowmar representative in most major cities.



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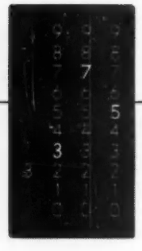
New low-cost

DIGITAL VOLTMETER



SADIC DIGITAL VOLTMETER (TYPE 33-110) is CEC's newest unit for low-voltage analog-to-digital conversion. It offers true economy plus high accuracy. Output includes illuminated numerical display (above) and decimal-coded contact closures. Suitable for bench use or rack mounting (two units fit side by side in 19" rack) the 33-110 is useful for both laboratory indication and as a building block for automatic data-processing systems.

SPECIFICATIONS

... digital range	000 to 999 (1000 steps)
... accuracy	1/10th % of full scale
... sensitivity	10 millivolts provides full-scale output
... balance time	0.8 second, max.
... power source	105-115 volts a-c

Send for Bulletin CEC 3009-X1

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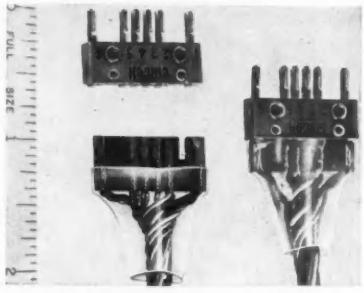
ASSORTED COMPONENTS



SUBMINIATURE connectors use printed circuits.

The photo above indicates printed circuit male connectors are now on hand. Contact surfaces are gold. Up to 12 leads are accommodated by this under-1-in. connector. A second, larger series accommodates 12 circuits on a set of connectors about 1½ in. wide. The smaller 2 and 4 contact models are less than ⅜ in. wide. *Circon Component Co., 17544 Raymer St., Northridge, Calif.*

Circle No. 52 on reply card

SMALLER TRANSISTORS: Raytheon's new units are so small that four can cover a dime without overlapping. Models 2N130, 2N131, 2N132, and 2N133 feature an average noise factor of 6.5 db. They are intended for audio or low radio frequencies. *Raytheon Mfg. Co., Newton 58, Mass.*

Circle No. 53 on reply card

PRINTED CIRCUIT CONNECTORS: These connectors, available in single and double row models, feature 6, 10, 15, or 22 contacts. They will accept variations of from 0.054 to 0.071 in. in the standard ⅛-in. thick printed circuit card. Wiring styles include solderless wire wrap, solder lugs, or taper pins. *DeJUR-Amsco Corp., Electronic Sales Div., 45-01 Northern Blvd., Long Island City 1, N. Y.*

Circle No. 54 on reply card

SMALL GEAR BOXES: Ranges from 4:1 to 12,000:1 are available with torques to 200 in.-oz. Size is about 1½ by 1½ in. Motor shaft can

be used in place of conventional input shaft and coupling. *Southwestern Industries, 5880 Centinela Ave., Los Angeles 45, Calif.*

Circle No. 55 on reply card

FREQUENCY CONVERTER: Converting 60 cycle current into 400 cycles is the function of a new "No-brush" frequency converter. Unit is no larger than driving motor alone, says the maker. Input voltages can change 10 per cent but if input frequency is constant, output will be true to within 2 per cent. A 500 watt output model weighs 49 lb. *Georator Corp., Manassas, Va.*

Circle No. 56 on reply card

POWER TRANSISTORS: A new set of medium power transistors is designed for Class A or B output or driving stages. When mounted on an aluminum chassis, a pair of 2N86's in push-pull Class B can give out approximately 1.5 watts, even at temperatures up to 70 deg C. *Transitron Electronic Corp., Melrose 76, Mass.*

Circle No. 57 on reply card

NEW TUBING and fittings speed air assembly.

Here's a new line of instrumentation fittings of unplasticized polyvinyl chloride, and for use with them, corrosion resistant flexible tubing. These products, says the maker, permit an entire air instrument assembly to be put together without the aid of wrenches, flaring or bending tools, stretchers, ferrules, or sleeves. All that's needed are knife and scissors. The fittings and tubing are furnished in both $\frac{1}{4}$ and $\frac{3}{8}$ in. sizes. A wide variety of special purpose fittings for the tubing will withstand up to 150 psi at 75 deg F. *Tube Turns Plastics, Inc., Louisville, Ky.*

Circle No. 58 on reply card

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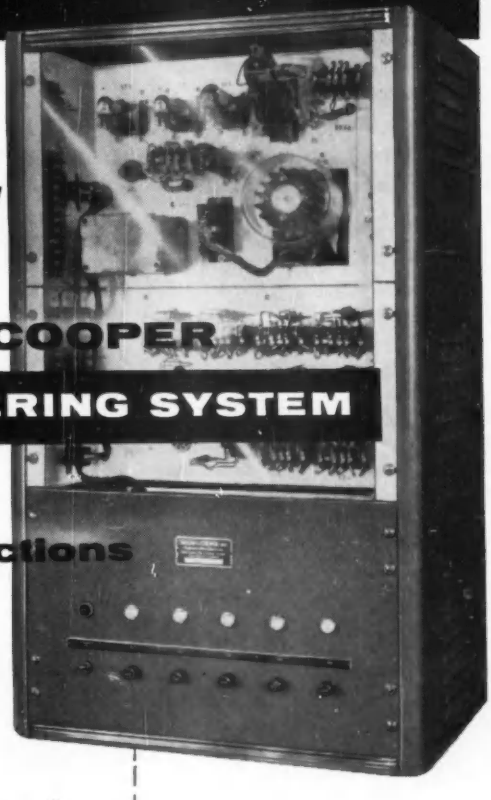

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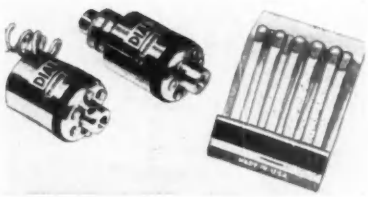
Circle No. 59 on reply card



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Circle No. 60 on reply card

FOOTSWITCH: A new footswitch with ears for floor or machinery mounting has construction ruggedness that enables it to withstand heavy abuse, says the maker. It's called the FS 15 AM and can be obtained with contacts rated for up to 15 amps. *Vemaline Products Co., P. O. Box 222, Hawthorne, N. J.*

Circle No. 61 on reply card

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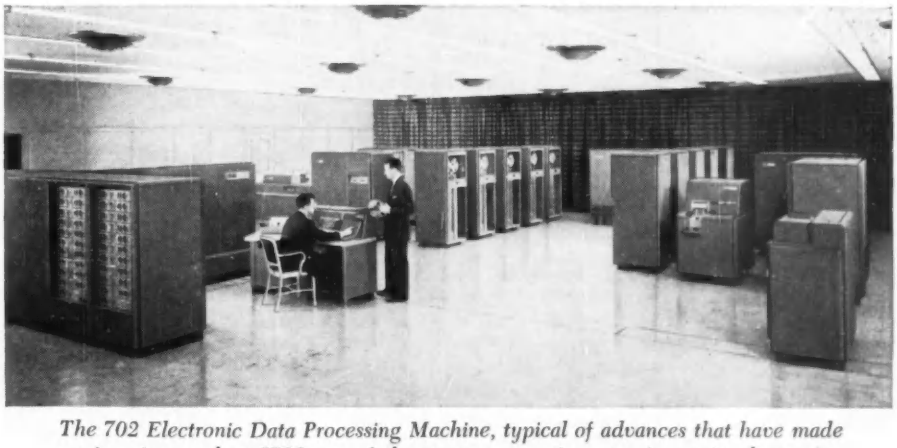

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ABSTRACTS

Pneumatic Dynamics . . .

From "Dynamics of Pneumatic Control Systems", by Page S. Buckley, E. I. du Pont de Nemours & Co. Paper delivered at the 10th Annual Instrument Conference and Exhibit of the Instrument Society of America. ISA Paper No. 55-6-2.

Because the dynamics of pneumatic instruments depend on how they are used in a particular system (i.e., how they are loaded), the basic problem is not to test individual instruments, as such, but rather to test segments of a control system. Thus, a measurement should be made from one point where the system is non-interacting to another point where it is non-interacting. This eliminates loading problems like that due to a significant volume at the end of a pneumatic line.

Although the actual loads on the instruments differ, both board-mounted and field-mounted control systems can be divided into three essentially non-interacting sections:

► From transmitter output to controller input. The transmitter, always field-mounted, connects to the controller by a relatively short line if the controller is field-mounted, and the system is faster. But the tubing branch that goes back to the board for manual-automatic control and indication has a serious effect on transmitter dynamics.

► From controller input to valve input. Again, the field-mounted instrument has a very short connection to the valve input. The controller output goes through a cutoff relay operated from the manual-automatic station on the board, to a branched load. One arm goes directly to the valve input; the other back to the valve position indicator on the board. The restriction in the cutoff relay and the branched load effect dynamics.

► From valve input to valve-stem position. This is the same for either system.

The parameters that vitally effect the dynamic response of a pneumatic control system are: signal level, signal size, transmission line diameter and length, transmission line termination, and branch loads. Graphs of experimental data are included for each of the parameters except signal level. In general, the response is faster for a higher level of average pressure; e.g.,

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- Small size: 1½" by 1¼" dia.
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(100) TRANSISTOR POWER SUPPLY. Dressen Barnes Corp. News Release 1012, one sheet. Model T 100A, described here, is a dual-voltage unit with outputs of 0-100 and plus or minus 0-100 vdc. Drift, recovery time, and ripple near negligible.

(101) CONTROL COMPONENTS. Industrial Control Co. Spiral data book, 15 inserts. Leading off this rundown are four models of servo amplifiers. Servo multiplier, dynamic analyzer, servo tester, and others follow.

(102) TEST EQUIPMENT. Peschel Electronics, Inc. General 1955 Catalog, 8 pp. Covers 13 instruments for testing for leakage and high voltage.

(103) INDUSTRIAL INSTRUMENTS. Century Electronics & Instruments, Inc. Catalog CGC-300, 20 pp. Describes recording instruments that perform major functions in Century's vibration and stress analysis system. The system is treated in detail.

(104) PROPORTIONAL CONTROLLER. The Foxboro Co. Bulletin 4-11, 4 pp. Describes an electric proportional control system. Reset action is available.

(105) RING-JET PUMPS. F. J. Stokes Machine Co. Bulletin 756, 8 pp. Traces the history of these high-pressure pumps, necessitated by modern industrial vacuum processing. Conventional speeds exceeded by 10-100 per cent.

(106) MAGNETIC AMPLIFIERS. Feedback Controls, Inc. Publication 101 8/55, 8 pp. Describes seven magnetic amplifiers designed for servo systems or for use as output stages.

(107) TAPE RESISTOR. Hansen Electronics Co. Bulletin HEC-1, 4 pp. Covers a carbon composition resistor said to be ideal for miniaturization and high temperatures. It is light (0.2 gram or less) and small (0.50 by 0.130 in.).

(108) TITANIUM TREATISE. E. I. du Pont de Nemours & Co., Pigments Dept. Progress Report 2, 8 pp. A discussion of this new, lightweight metal that is finding increasing use in chemistry, aviation, and food processing.

(109) CHOPPER AMPLIFIER. Offner Electronics, Inc. Dynograph Data, June, 1955, one sheet. This amplifier's vital role in the Dynograph direct-writing oscillograph is explained in text and drawings. Though a dc unit, the amplifier is drift-free.

(110) SPECIAL-PURPOSE INSTRUMENTS. Micrometrical Development Corp. Bulletin, 4 pp. Describes the Proficorder for recording surface profiles, Ball Wavometer for measuring ball bearing irregularities, and the Runout Checker for measuring runout during opeation.

(111) "MOTORIZATION". ACEC Electric Corp. Information Journal, No. 1, 14 pp. This new magazine will detail progress in electric motor unit drives. An informative lead article classifies variable speed problems in the light of torque-speed relations.

(112) VERSATILE VALVES. Automatic Switch Co. Bulletins V5003 and V5004, one page each. The valves in V5003, equipped with one or two solenoids, handle air, gas, water, or hydraulic fluids of 10-500 psi pressures. The ones in V-5004 are general purpose, two-way solenoids of an improved, simplified design.

(113) PRESSURE TRANSDUCERS. Datran Engineering Corp. Six data sheets. Discusses three units that convert pressure to frequency, and one that measures pressures in non-corrosive liquids or gases. Ranges are from plus or minus 0.5-2.5 to 1,500-3,000 psi. Also covered: a position servo and a telemetering oscillator.

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(114) VALVE COUPLINGS. C. B. Hunt & Son, Inc. Bulletin, 4 pp. Manipulation of a knurled sleeve locks or opens coupling, releasing or trapping air. Pressure capacity is 250 psi.

(115) MEASUREMENT CONTROL. Daytronic Corp. Bulletin, 6-pg. gatefold. Tells how the versatile LVDT (linear variable differential transformer) fits into systems that measure, control, and record pressure, or issue an alarm.

(116) BOILER PLANT INSTRUMENTS. The Hays Corp. Publication 55-605-83, 24 pp. Photos, schematics, and text explain combustion guides, draft gages, combustion control systems, and flow, level, temperature, and pressure units.

(117) SWITCHING TRANSISTORS. Texas Instruments, Inc. Data sheets DL-S 545, 546, 547, and 548. The germanium units detailed here are designed for computers and general purpose switching. They are hermetically sealed, stable, and durable.

(118) POTTING MANUAL. Cannon Electric Co. Manual PM-1, 1955, 12 pp. The fact that Cannon plugs are used to illustrate the method takes little away from the educational value of this booklet.

(119) MEMORY DEVICES. Brush Electronics Co. Bulletin, 4 pp., and Catalog Sheet DD 14020. The bulletin details the "Tapedrum", which can store 5 million binary digits on 50 ft of magnetic tape. (The tape can be up to 600 ft. long.) The Datacord, subject of the sheet, is a tape transport mechanism.

(120) DIGITAL DECADE COUNTERS. Brush Electronics Co. Catalog Sheet DD 14001. Tells about high-speed counters that accept pulses at 0 to 100,000 counts per sec and read out remotely. Readout need not be digital: it may be coded or analog.

(121) LEVEL DETECTOR. Instruments, Inc. Sheet. Information about a new, small and compact sensitive capacitance probe for fluids. It detects, or warns of, level. Sensitivity is greatest in a foam media.

(122) MAGNETIC SHIELDS. Magnetics, Inc. Catalog MS-104, 38 pp. Presents detailed engineering drawings of nearly three dozen dry hydrogen annealed magnetic shields and discusses metals used.

(123) ELECTRO-PNEUMATIC CONTROL. Leeds & Northrup Co. Bulletin, 8 pp. Covers the Series 60 current-adjusting system that operates with a control unit and a converter to change current input into air input and actuate a pneumatic control valve. Suggested for oil and chemical industries.

(124) SPRING DESIGN DATA. Spring Div. of Hunter Spring Co. Clipped data sheets, 10 pp. Line drawings, graphs, and charts cover spring index, coil diameter variation, modulus, and physical characteristics.

(125) CON ENGINEERING PRODUCTS. Consolidated Engineering Corp. An impressive array of bulletins received this month covers a playback recorder, recording oscillograph, strain gages, galvanometers, power supplies, pressure pickup, pressure standard, and bridge balance.

(126) NEW ESI PRODUCTS. Electro-Measurements, Inc. Catalog, 4 pp. Describes such precision electrical instruments as an impedance bridge, ac and dc generator-detectors, and several potentiometers, Wheatstone bridges, rheostats, and capacitors.

(127) HONEYWELL LITERATURE. Minneapolis-Honeywell Regulator Co. Bulletins from Honeywell's Brown Instruments and Industrial Divs. discuss a new Moist-O-Graph, a radiation detector, and automatic canning. M-H has issued an index (Bulletin 100-D, 24 pp.) of catalogs and bulletins presently available.

(128) DIELECTRIC CAPACITORS. The Gudeman Co. Engineering Bulletin XC-201-4, 6-pg. gatefold. Gives salient data about high temperature (165 deg C) plastic film, hermetically sealed, tubular capacitors. Insulation resistance is high, power factor and dielectric absorption low.

(129) PRESSURE GAGE. Instrumentation & Systems Div. of Norden-Ketay Corp. Bulletin 364, 4 pp. Gives standard specs and ranges for N-K's bourdon-tube Acragage, the first solid-front gage of its kind at standard prices.

(130) STRIP-CHART RECORDERS. The Bristol Co. Bulletin, 12 pp. Bristol's line of 6-in. recorders for pressure, liquid level, temperature, flow, and mechanical motion are treated in installation drawings and photographs. They can receive remote pneumatic or electric signals

(131) PRESSURE TRANSDUCERS. Statham Laboratories, Inc. Bulletins MPT-1, MPT-130, MPT-131, MPT-132, and PA-1, all stapled into a 12-pg. booklet. These transducers measure in psia, psid, and/or psig. PA-1 describes transducer adapters.

(132) METALWORK GAGING. Freeland Gauge Co. Bulletin, 8 pp. A pictorial survey of Freeland's gages and control instruments for the metalworking industry.

(133) RESISTORS. International Resistance Co. Bulletins B-2a, B-8a, F-3, P-1a, and P-2a, 6 pp. B-2a covers Type MW, a flat wire wound strip rated at 40 deg C; B-8a, ½-watt molded boron-carbon units; F-3, high frequency miniature resistors; and P-1a and P-2a deal with high temperature devices.

(134) RESISTOR GUIDE. International Resistance Co. Bulletin, 4 pp. This Official Resistor Engineering Guide for 1955-56 gives specs for practically every resistor IRC manufactures.

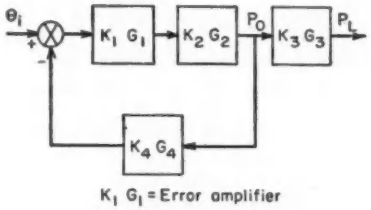
the response at 50 psi is definitely better than at 9 psi.

For large signals, 1½ to 2 psi or larger, the saturation due to already-wide-open pilots slows response. System response improves as the signal gets smaller, until, at 1/10 psi or less, static friction and hysteresis (most likely in the control valve) add lags.

A pneumatic transmission line attenuates a signal much like an electric transmission line, and the attenuation increases with the length of the line. For the case graphed in this paper, various lengths of ⅜-in. tubing connected to a 6-in. valve, 20 ft of tubing allowed the valve to respond twice as fast as 250 ft. In a similar test of line diameter effects, ⅜-in. tubing gave 1½ times the response of ¼-in. line.

The pneumatic transmission line also has a characteristic impedance, and ideally, like the electric line, it should be terminated in this impedance. But this rarely happens. When the termination is the topworks of a spring-and-diaphragm valve, the terminating impedance is very much less than the characteristic impedance of the line and the attentuation and phase shift of the signal are increased. If the termination is a valve positioner, the small bellows or diaphragm may have an impedance higher than the characteristic impedance of the line and peaking can result. For short lines, severe peaking may result unless capacity is added.

The manual-automatic station is part of the controller load and its effect on system dynamics can be quite marked. For example, adding one manufacturer's station in series with 250 ft of ⅜-in. tubing and a 4-in. valve reduced response by a factor of three.



$K_1 G_1$ = Error amplifier
$K_2 G_2$ = Power amplifier
$K_3 G_3$ = Load
$K_4 G_4$ = Feedback circuit

Similarly, branched loads like those that occur with field-mounted controllers can cause serious loss in dynamic response. In a field-mounted controller with a cutoff relay and 10 ft of ¼-in. tubing, a test was made with and with-

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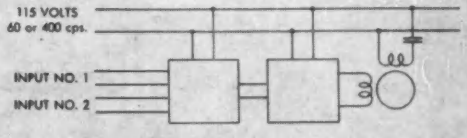

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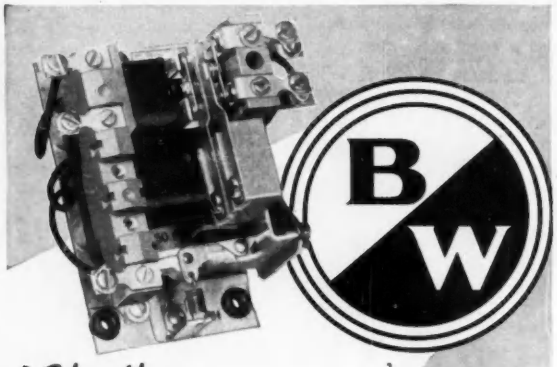

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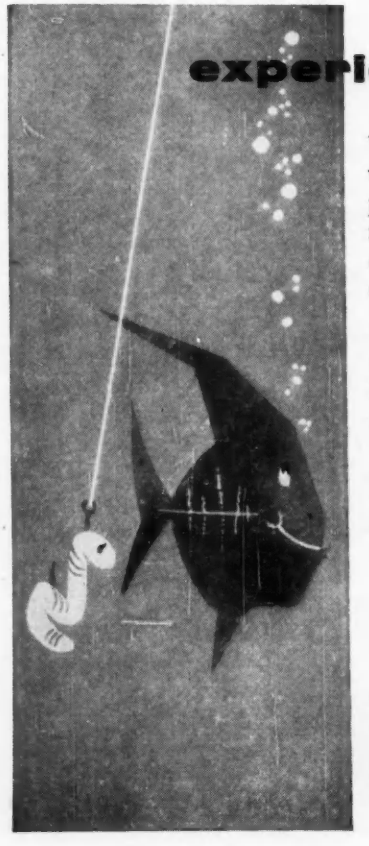

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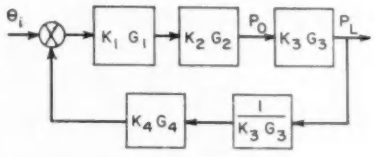
ABSTRACTS

out a branch line that went 250 ft back to the board. Removing or isolating the branch line made the response faster by more than five times.

The general pneumatic transmitter can be represented by the first block diagram, where K_3G_3 is the dynamic response of the load (tubing, single or branched paths, valves or other restrictions, and terminations), and P_L is the resulting output pressure to the controller. The response is:

$$\frac{P_L}{\theta_i} = \left[\frac{K_1G_1\,K_2G_2}{1 + K_1G_1\,K_2G_2\,K_4G_4}\right] K_3G_3$$

As shown previously (by Vannah and Catheron, ISA Paper 51-6-2), the first block can be rearranged as in the second diagram, which has the same response as the first. Then making the feedback dynamics, G_4, equal to the transmission line dynamics, G_3, compensates for the dynamics in the feedback path. In effect, this closes the loop around the transmission line and increases response. Theoretically, it should be possible to improve response by 500 to 1,000 per cent, but the pilot valve capacity of the average transmitter limits the improvement.



Several experimental setups have obtained approximately the results predicted above. Graphical results of a specific arrangement show an improvement in dynamic response of 300 to 400 per cent, limited in this case by the roughness of the approximation of the transmission line dynamics used in the feedback path.

. . . And Better Memories

From "Ferroelectric Storage Devices"' by W. J. Merz and J. R. Anderson, Bell Telephone Laboratories. "Bell Laboratories Record", September, 1955.

By definition, a ferroelectric crystal shows a spontaneous electric polarization due to an alignment of electrical dipoles. This is an electrical analog

of the spontaneous alignment of magnetic dipoles in a ferromagnetic crystal. In fact, the two types of crystals have a number of similar properties. Both types of crystals have an extremely high permeability (electric and magnetic, respectively), a hysteresis loop, and domains. Both have a "Curie" temperature, a critical temperature above which the crystals lose their ferroelectric or ferromagnetic properties.

Rochelle salt and potassium dihydrogen phosphate are ferroelectric crystals, but barium titanate ($BaTiO_3$) is more practical for several reasons: it has a high Curie point (120 deg C), large crystals can be grown, and its electrical properties are suitable for use in switching circuitry. A new crystal, guanidine aluminum sulphate hexahydrate, $(CN_3H_6)\ Al(SO_4)_2.6H_2O$, may eventually displace barium titanate because of better switching stability at high repetition rates.

In an ordinary dielectric, polarization, or displacement of electric charges, increases linearly with the applied field. The slope of the line is the electrical susceptibility, or dielectric constant. Ferroelectrics have a characteristic hysteresis loop rather than the linear field-polarization relationship. If the crystal is polarized in one direction and then the field is removed the polarization remains. This is called the "spontaneous polarization".

Because a crystal can be polarized in two directions, with either a positive or a negative field, it has two stable states. It can therefore be used to "remember" the binary numbers *0* and *1*. For example, suppose the crystal is to be charged positively, i.e., the spontaneous polarization is at the positive end of the hysteresis loop. If a positive pulse is applied to the crystal, the spontaneous polarization increases only very slightly during the pulse, and returns to its starting positive spontaneous polarization. It behaves, then, as if it is saturated positively, and a very small charge flows due to the applied pulse.

But if the crystal has a negative spontaneous polarization, the polarization changes, a relatively large charge must flow into the crystal, the hysteresis loop is transversed counter-clockwise to the positive end, and, at the end of the pulse, the crystal is left with a positive spontaneous polarization. Thus, the crystal "memory" is interrogated with positive pulses, no

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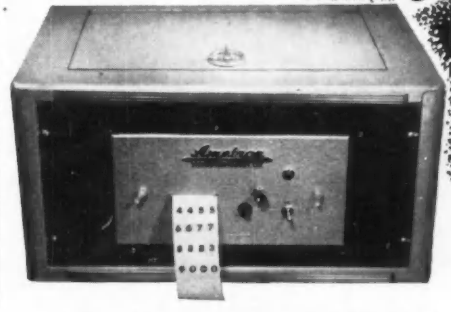

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ABSTRACTS

current flow during the pulse is read as a stored *1*, and current flow as a stored *0*. Note that the read-out pulse may change the state of the memory, and circuitry must be provided to return the crystal to its original state if the memory is to be retained after readout. Note also that a negative storage pulse is needed to store a binary *1*.

A cell formed by 0.004-in.-wide etched wires crossing at right angles on opposite sides of a 0.002-in.-thick crystal requires about 5 v to switch from one state to the other. The total charge switched is about 5×10^{-9} coulombs. For a 50-v applied pulse, switching time is about 0.25 microsec and peak current is about 54 ma. For a 20-v pulse, the switching time is 1.0 microsec and the peak current is 12 ma. Although the usual load on the ferroelectric memory cell is a vacuum tube grid, the output current is sufficient to operate a relay directly if the electrodes are of the order of 0.01 in.^{2}. The switching time of the ferroelectric when operating a relay may be several milliseconds.

An experimental crystal has been built that is $\frac{1}{8}$ in. sq and 0.002 in. thick. Sixteen electrodes 0.004 in. wide and 0.012 in. apart are etched across the face, and 16 similar electrodes are etched at right angles across the opposite face. The cross points of these electrodes then form 256 noninteracting cells. If E volts are necessary to switch a cell, and $E/2$ volts are applied simultaneously to one electrode and to another electrode on the opposite face, then the cell where these electrodes cross will switch. All other cells on both electrodes will have only $E/2$ volts applied and will not be affected. With this scheme, only 32 read-in and read-out circuits are needed for a 256-bit memory.

Of all present storage methods, ferroelectrics and magnetic cores are most comparable in access times, switching speeds, and switching power consumption. Both can be operated by transistors. However, the ferroelectrics have advantages over magnetic core storage devices: they do not require assembly of individual units; they can operate over a very wide range of speeds, from microseconds to milliseconds; and they require, at lower speeds, considerably less peak power.

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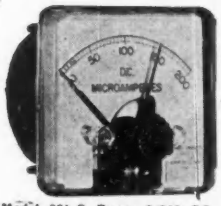

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NEW BOOKS

Machine Computation

BIBLIOGRAPHY ON MACHINE COMPUTATION, 1945-1954. *Compiled by Marjorie Comstock. 8⅜ by 10¾ in., 36 pp. Published by Brookhaven National Laboratory, Upton, New York. Report No. BNL 321 (L-102), May, 1955.*

This monograph includes a 34-page "Bibliography on Machine Computation, 1945-1954," listing 1,158 periodical references arranged alphabetically by authors; and a 2-page "Index" of 153 topics, to each of which is appended the numbers of the pertinent references in the bibliography.

The book lists technical and nontechnical articles and unclassified reports on the various aspects of machine computation published between 1945 and November, 1954. Three major bibliographies on machine computation have appeared previously:

1. "Bibliography on the Use of IBM Machines in Science, Statistics, and Education", by A. F. Beach, E. V. Hankam, and K. M. Sweeney, 60 pp. International Business Machines Corporation, New York, N. Y., 1954.
2. "Computers: Including Fire Control Computers, Flight Calculators, Mathematical Computers, Navigation Computers; a Report Bibliography", by F. A. Clark, 30 pp. ASTIA Reference Center, Library of Congress, No. ARC 854, 1954.
3. "Bibliography on Electronic Computing", by R. Serrell and K. J. Ruprech. Edition 3, 91 pp. Radio Corporation of America, R. C. A. Labs. Division, Princeton, N. J., 1953.

The monograph under review avoids duplication of references in these reports.

Gyroscope Treatise

THE GYROSCOPE APPLIED. *By K. I. T. Richardson. 384 pp. Published by Hutchinson's Scientific and Technical Publications, London, England. 30 shillings; sold in U. S. by Philosophical Library, Inc., 15 East 40th Street, New York 16, N. Y.*

Twenty-three chapters are grouped into five major sections. The sections are headed: The Fundamentals, Marine Applications, Aeronautical Applications, Military Applications, and Other Applications of the Gyroscope. This text includes a slim bibliography of 30 items, but a fine index.

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NEW BOOKS

a simple outline of the basic properties of the gyroscope, supported by examples.

The second part, on Marine Applications, describes the Sperry, Brown, and Anschutz and Plath gyro compasses and their use for automatic steering control and ship stabilization.

The third (and largest) part, on Aeronautical Applications, describes various aircraft gyroscopic and navigational instruments, gyro-verticals, rate of turn indicators, direction indicators, automatic pilots, flight directors, and other aeronautical uses of the gyroscope.

The fourth part, on Military Applications, details usage in aircraft bombsights and gun sights and in the control of missiles as exemplified by torpedo steering systems and the control circuits of the German V1 flying bomb and the V2 rocket missile.

The fifth part, on Other Applications, describes miscellaneous uses as in the monorail car, the two-wheel motor car, and—more currently—a German gyro-theodolite used in mine surveying.

An appendix, on simple mathematics, gives an elementary mathematical treatment of certain fundamentals of gyrodynamics.

In general, the descriptive content is accurate in statement, though somewhat circumscribed at points. Although the theoretical content is advanced almost without use of mathematics, the reviewer found the simple analysis incorrect in a few places.

Thomas J. Higgins
Professor of Electrical Engineering
University of Wisconsin

Other Gyro Books

(Professor Higgins suggests the following books to supplement the applications book reviewed above, and gives his reasons.—Ed.

1. "The Gyroscope; An Experimental Study: From Spinning-Top to Monorail", by V. E. Johnson. E. and F. N. Spon Ltd., London, England, 1911, 87 pp. Particularly useful for the teacher who wishes to run demonstrations or experiments on the gyroscope.
2. "The Gyroscope; its Practical Construction and Application: Treating of the Physics and Experimental Mechanics of the Gyroscope, and explaining the Method of its Application to the Stabilization of Monorailways, Ships, Aeroplanes, Marine Guns, etc.", by P. L. Schilvosky. E. and

F. N. Spon, London England, 224 pp. Similar to Johnson's text.

3. "Applied Gyrodynamics: for Students, Engineers and Users of Gyroscopic Apparatus", by E. S. Ferry. John Wiley and Sons, Inc., New York, N. Y., 1932, 277 pp. A good mathematical account of basic theory at an intermediate level.

4. "Mechanics of the Gyroscope: The Dynamics of Rotation", by R. F. Deimel, Macmillan Company, Ltd., London, England, 1929. 192 pp. Reprinted, with errata corrected, by Dover Publishing, New York, N. Y., 1950, 192 pp. Essentially the same values as Ferry's text.

5. "Report on Gyroscopic Theory", by G. Greenhill. Reports and memoranda No. 146, Advisory Committee for Aeronautics, Great Britain. H. M. Stationery Office, London, England, 1914, 277 pp. An advanced monograph on certain specialized topics.

6. "A Treatise on Gyrostatics and Rotational Motion: Theory and Applications", by A. O. Gray, Macmillan Company, Ltd., London, England, 1918, 530 pp. This is, perhaps, still the best and most exhaustive text in English on the analytic theory of the gyroscope.

7. "Uber die Theorie des Kreisels", by F. Klein and A. Sommerfeld. B. G. Teubner, Leipzig, Germany. This four-volume work, a total of 966 pages, was issued in 1897, 1898, 1903, and 1903. Though the applications are now dated, its exhaustive account of theory makes its value permanent and its current usefulness considerable.

8. "Der Kreisel, seine Theorie und seine Anwendugen: Vol. 1, Die Theorie des Kreisels (281 pp); Vol. II, Die Anwendugen des Kreisels (268 pp)", by R. Grammel. Springer-Verlag, Berlin, Germany, 1950. Excellent, high-level treatment of the theory; many modern applications.

9. "The Theory of the Gyroscopic Compass and its Deviations", by A. L. Rawlings. Macmillan Company, Ltd., London, England, 1929, 191 pp. Edition 2, revised 1944, 182 pp. Thorough account of the gyro compass.

A Sequel to Rhodes

INSTRUMENTS FOR MEASUREMENT AND CONTROL. Werner G. Holzbock, Askania Regulator Co., Chicago, 371 pp. Published by Reinhold Publishing Corp., New York. $10.00

Here is a long overdue round-up of industrial process control instruments. Essentially, it is patterned—in content as well as in title—after the pioneer book by Rhodes (*Industrial Instruments for Measurement and Control*,

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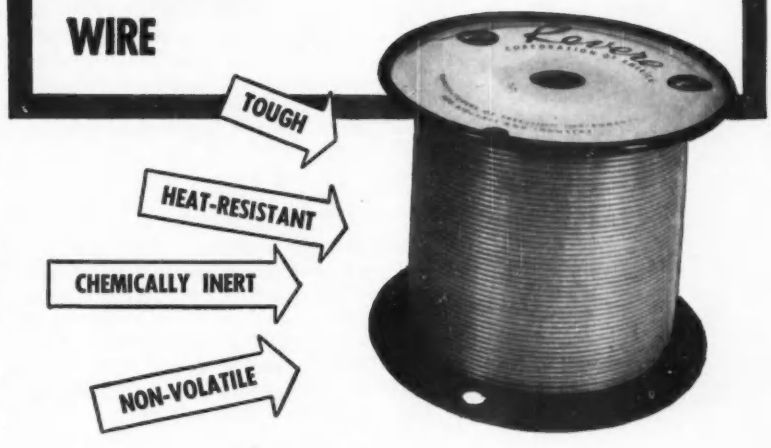

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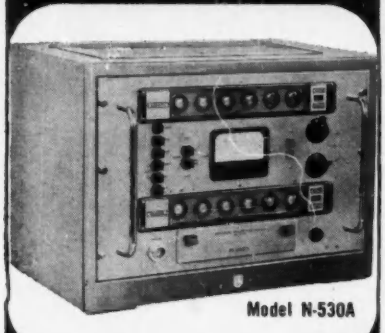

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T. J. Rhodes, 573 pp., McGraw-Hill Publishing Co.) which is still being ordered in its 1941 first edition. Holzbock lucidly, albeit briefly, covers the numerous developments since that time.

Like Rhodes', the new text takes individual variables such as temperature, pressure, flow and liquid level, and in separate chapters shows how they are handled by instruments for measuring and controlling. There are abbreviated Rhodes-like chapters on automatic control mechanisms (electric, pneumatic, and hydraulic), as well as programming units and final control elements. Barely touched on, however, is automatic control theory —the chapter on this in the 1941 text proved to be a rather important and advanced contribution. But the numerous control theory texts available today may justify this omission from Holzbock's volume.

The big contribution this new book makes is its elaboration on what Rhodes called "miscellaneous industrial instruments". Holzbock devotes special chapters to today's remarkably expanded line of equipment for measuring quality variables such as density, viscosity, speed, and 19 forms of product composition. The latter chapter, entitled "Analysis", crams quite a lot of information into 41 pages. It describes recent developments in measuring weight, volume, conductivity, pH, infrared absorption, ultraviolet analysis, mass spectrometry, turbidity, magnetism, etc. The descriptions, which include pictures and diagrams, are terse but factual and accurate.

Holzbock has done a good job of corralling the very latest wrinkles in process control equipment—some of the units described were only released as new products in the past few months. Included are such items as Fischer & Porter's "Press-I-Cell"; turbine, electromagnetic and mass flowmeters; gamma ray and sonic level measuring units; ultrasonic viscosimetry, electronic digital speed measurement; GE's new turbidimeter. A short chapter on "trends" weaves in the new techniques of miniaturization, centralization, and data processing. The volume ends with a short glossary of automatic control terms.

This book should prove a readable, quick schooling for the newcomer to the process control field, a handy review for the practicing instrument engineer, and an excellent survey for the outsider who would like to know what's available for automatic process control.

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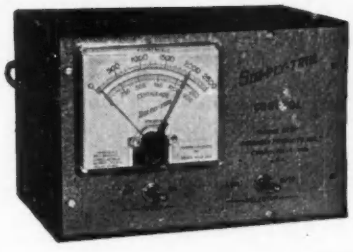

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NOVEMBER

American Institute of Chemical Engineers, 48th annual meeting, Hotel Statler, Detroit, Mich. Nov. 27-30

Institute of Radio Engineers, Professional Group on Instrumentation, Conference and Exhibition on "Data Handling", Atlanta Biltmore Hotel, Atlanta, Ga. Nov. 28-30

DECEMBER

Twenty-fifth Exposition of Chemical Industries, Commercial Museum and Convention Hall, Philadelphia, Pa. Dec. 5-9

Engineers Joint Council, International Atomic Exposition, (10-16), and Nuclear Engineering and Science Congress, (12-16), Public Auditorium, Cleveland, Ohio. Dec. 10-16

American Chemical Society, 1955 Christmas Symposium on Process Instrumentation and Control, Princeton University, Princeton, N. J. Dec. 29-30

JANUARY

National Simulation Conference, Institute of Radio Engineers, Dallas-Fort Worth Chapter (Professional Group on Electronic Computers), Hotel Baker, Dallas, Texas. Jan. 19-21

American Institute of Electrical Engineers, Winter General Meeting, Statler Hotel, New York. Jan. 30-Feb. 3

FEBRUARY

Institute of Radio Engineers, Eighth Annual Southwestern Conference and Electronics Show, Municipal Auditorium, Oklahoma City, Okla. Feb. 9-11

Louisiana State University, 1956 Conference on High-Speed Computers, Baton Rouge, La. Feb. 15-17

MARCH

Institute of Radio Engineers, National Convention, Kingsbridge Armory and Waldorf-Astoria Hotel, New York. March 19-22

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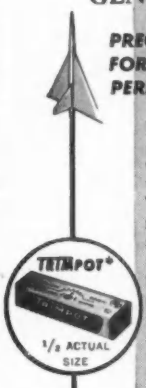

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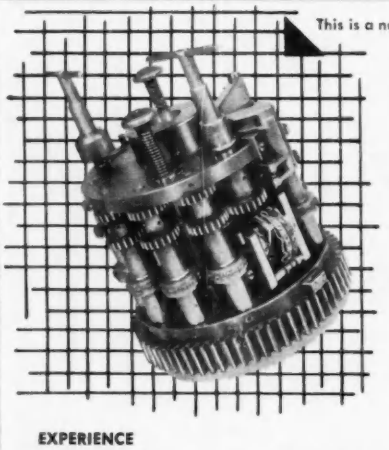

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Special Technical Conference on Magnetic Amplifiers, sponsored by American Institute of Electrical Engineers, Institute of Radio Engineers, Instrument Society of America, Hotel Syracuse, Syracuse, N. Y. April 5-6

American Institute of Electrical Engineers, Conference on Recording and Controlling Instruments, Bradford Hotel, Boston. April 26-27

The bibliography below relates to the article by Gilbert Roth on p. 46.

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4. *FLUID MECHANICS*, R. C. Binder, Prentice-Hall, Inc., 1943.
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6. *CONTRIBUTION TO STUDY OF BUTTERFLY VALVES*, D. Gaden, "Water Power", December 1951.
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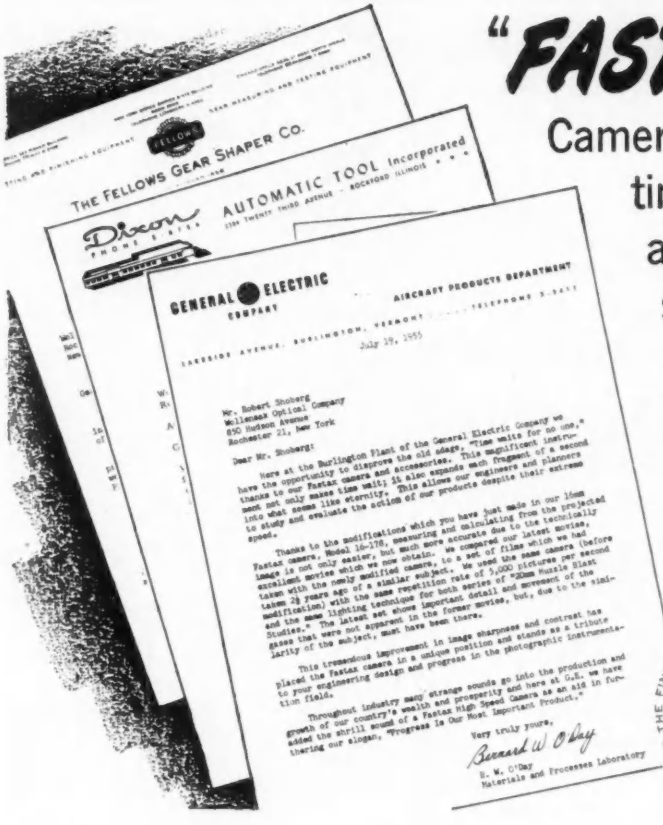
8. *SIMPLE AUTOMATIC GAS FLOW-LIMITING VALVE*, F. Call, "Journal of Scientific Instruments", August 1952.
9. *PRACTICAL CONSIDERATIONS IN SELECTION OF CONTROL VALVES*, G. F. Brockett, "Instruments", June 1953.
10. *SIZING CONTROL VALVES*, G. F. Brockett, "Oil and Gas Journal", July 6, 27, August 3, 17, 24, 1953.
11. *DESIGN AND CONSTRUCTION OF CONTROL VALVES*, D. E. Hostedler, "Petroleum Refiner", August 1953.
12. *CONTROL VALVES FOR HIGH AIR-MASS FLOWS*, F. E. Swain, "Engineering", Dec. 4, 1953.
13. *FACTS ABOUT MODERN VALVES*, "Mill and Factory", May 1954.
14. *CONTROL VALVES*, R. E. Love, "Instruments and Automation", May 1954.
15. *VALVE POSITIONERS*, M. Strader, "Instruments and Automation", July 1954.
16. *CONTROL VALVES AND THEIR APPLICATION*, L. H. Allen, Jr., "Instruments and Automation—Handbook of Measurement and Control", December 1954.
17. *FLOW CONTROL WITH VALVES AND PUMPS*, R. Hadekel, "Automation", January 1955.
18. *HOW TO ANALYZE CONTROL SYSTEMS GRAPHICALLY*, H. M. Paynter, "Control Engineering", February 1955.



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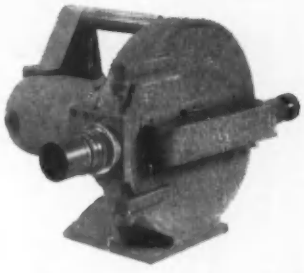

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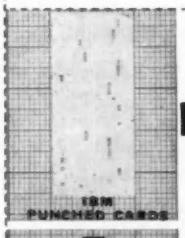

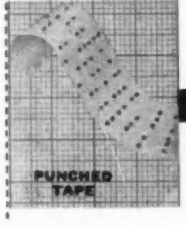

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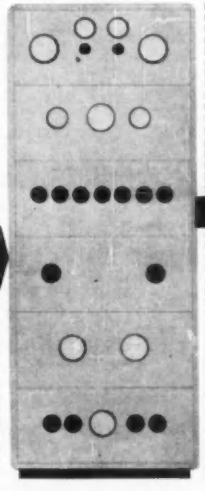

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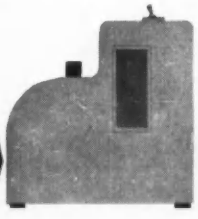

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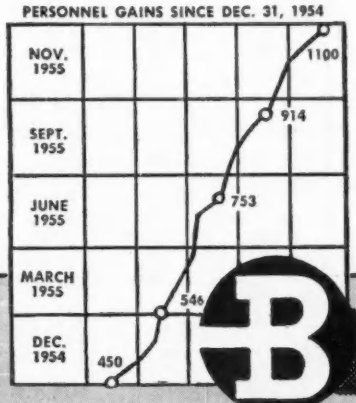

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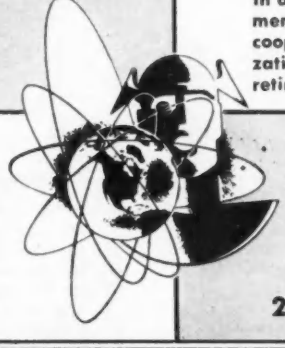

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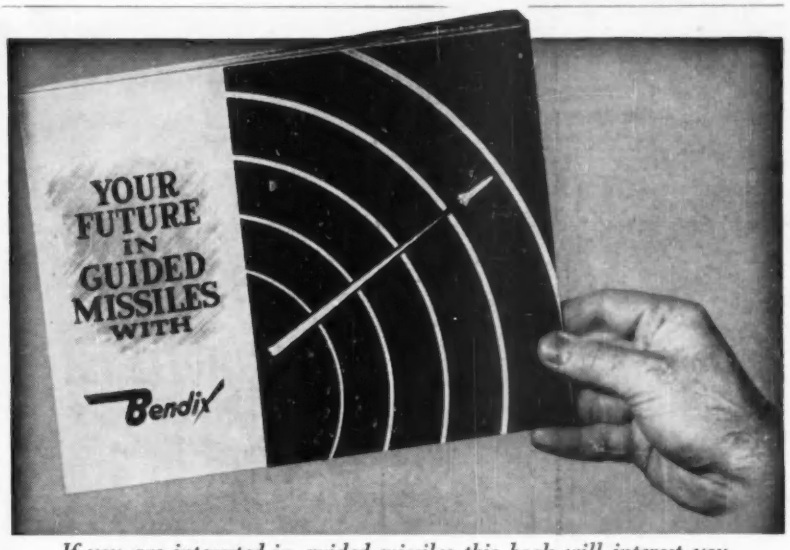

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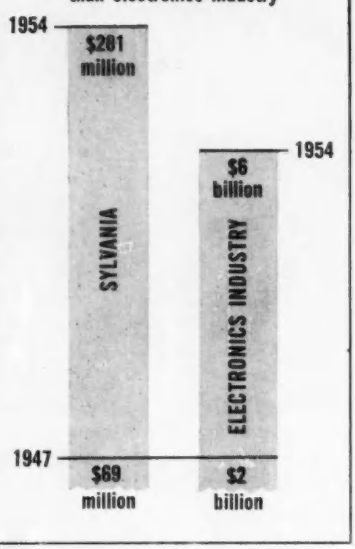

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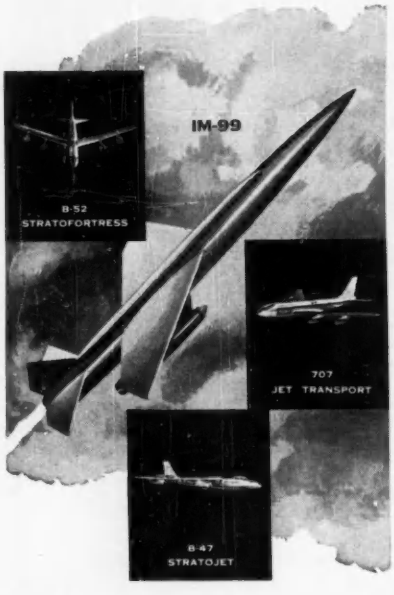

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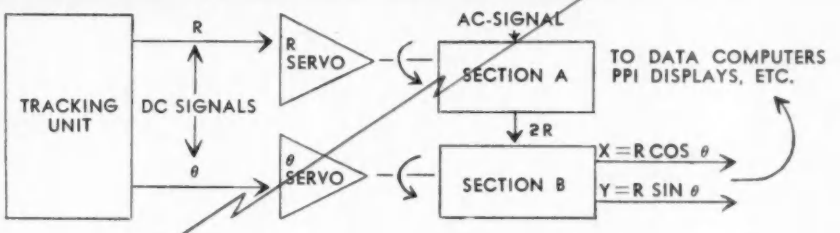
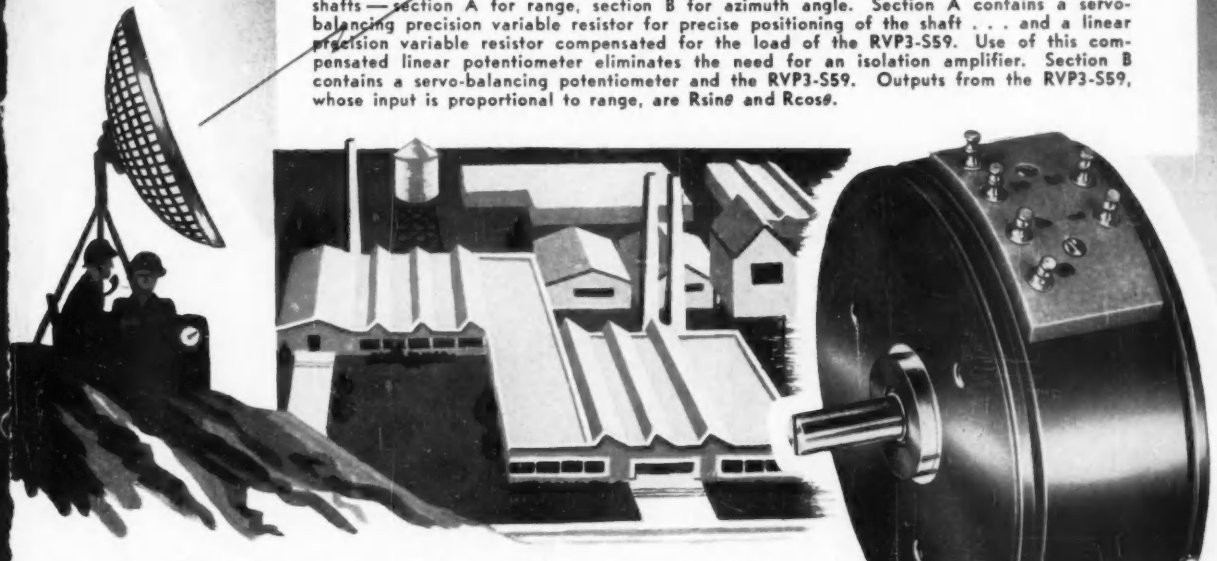
$X=R\cos\theta \quad Y=R\sin\theta$



Typical circuit for polar to rectangular transtormation. Servo amplifiers position the two shafts — section A for range, section B for azimuth angle. Section A contains a servo-balancing precision variable resistor for precise positioning of the shaft . . . and a linear precision variable resistor compensated for the load of the RVP3-S59. Use of this compensated linear potentiometer eliminates the need for an isolation amplifier. Section B contains a servo-balancing potentiometer and the RVP3-S59. Outputs from the RVP3-S59, whose input is proportional to range, are R$\sin\theta$ and R$\cos\theta$.



Simple trigonometric expressions but an important link in the radar system . . . polar to rectangular transformation. Basic polar information (range and azimuth angle) must be transformed into rectangular form for use in analog computers and PPI displays. Needless to say, the method used must embrace accuracy and reliability. TIC's precision sine-cosine variable resistor RVP3-S59 is especially designed for precision resolution of voltages into sine and cosine components.

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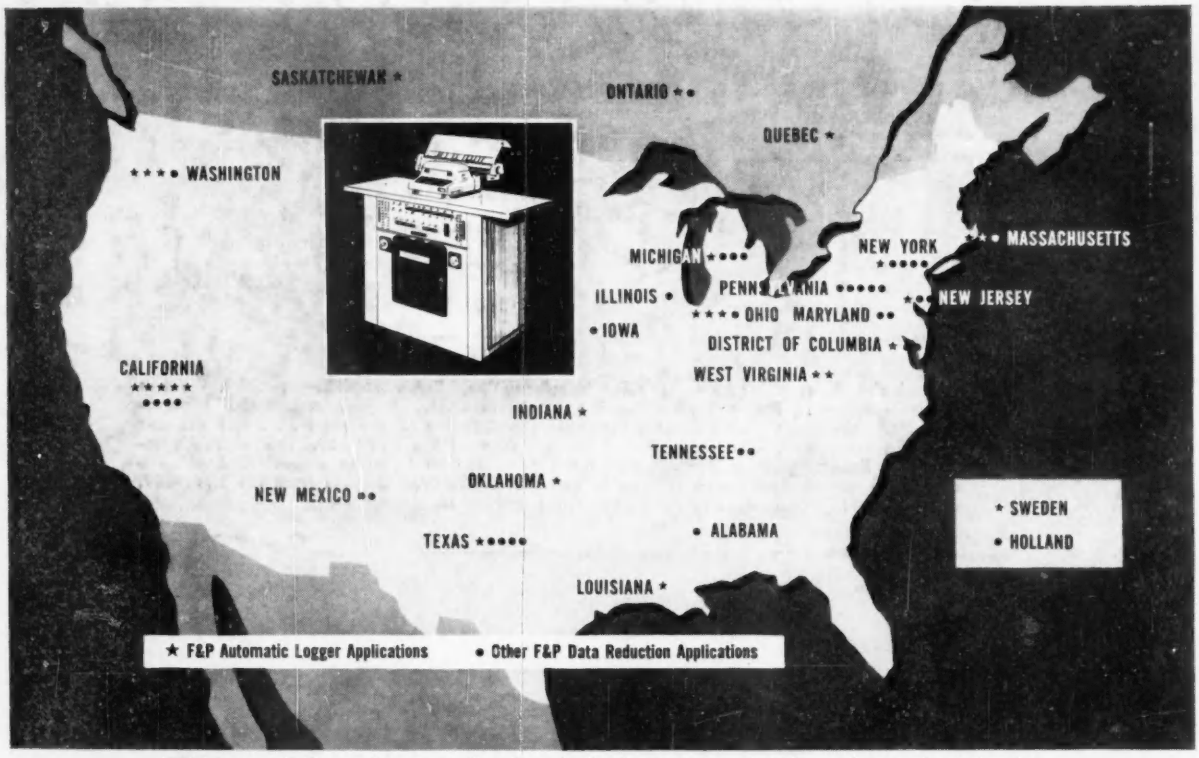

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